UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 699

Contribution from the Bureau of Soils
MILTON WHITNEY, Chief

Washington, D. C. ▼ October 16, 1918

ANALYSIS OF EXPERIMENTAL WORK WITH GROUND RAW ROCK PHOSPHATE AS A FERTILIZER

By

W. H. WAGGAMAN and C. R. WAGNER, Scientists in Investigation of Fertilizer Resources, assisted by R. F. GARDINER, Scientist in Soil Laboratory Investigations

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INTRODUCTION.

Much doubt and difference of opinion exists concerning the fertilizer value of ground raw rock phosphate. Some agronomists and agricultural chemists have reported satisfactory results from its use both in pot and field experiments, others have decided that while the material is beneficial to a number of crops when applied under certain conditions, it is so inferior to acid phosphate that it is unwise, under normal conditions, to depend upon it as a source of phosphoric acid when one can obtain the more soluble superphosphate. Several experiment stations have concluded that ground raw rock phosphate is entirely unprofitable on most of the soils in their particular States under their present crop systems.

The use of ground raw rock phosphate directly as a fertilizer, however, has slowly increased during the last decade until now the annual consumption is in excess of 91,000 tons, involving an expenditure by the farmer of over $750,000 annually.

Most of the demand has been in the corn belt of the middle Western States, particularly in Illinois, where the State Agricultural Experiment Station has strongly recommended this material and out-

lined methods of treatment and application which it claims will result in the maximum benefit from its use. But ground raw rock phosphate has been used to a small extent in many other States and would undoubtedly have been more widely employed were it not for conflicting conclusions concerning its agricultural value, conclusions which in many instances have been drawn from insufficient data.

Numerous experiments have been conducted, not only in the field but in the greenhouse and laboratory as well, to test the fertilizer value of ground raw rock phosphate. While some of the field experiments have been carried on in a careful, systematic way over a term of years, others have been conducted for such a brief period and apparently with so little regard for the numerous factors influencing crop yields that it is not only unwise to draw any definite conclusions from the results but unfair to class them with those obtained from carefully conducted long-time experiments. After a careful analysis of a number of long-time fertilizer experiments, Prof. Whitney,[1] of this bureau, states that " a period of not less than 15 years of observation is required to draw any safe conclusions from fertilizer plot tests." If the results of experiments so far published, therefore, be taken without carefully weighing their relative merits, the only conclusion one could possibly reach is that ground raw rock phosphate is of very questionable value.

In giving the results of field tests with ground raw rock phosphate, the writers found it difficult to draw the line between experiments warranting discussion and those which were not sufficiently important to justify consideration in detail. Finally the plan was adopted to discuss only those field experiments which were conducted for five years or more. In some instances this plan may appear not quite fair, but almost any other treatment of the subject would result in a manuscript so bulky and so filled with data of relatively little value, that it would only serve to confuse the reader.

HISTORY.

The use in this country of ground raw rock phosphate as a fertilizer dates back to the early days of the South Carolina phosphate industry.

Holmes[2] recommended finely ground South Carolina rock for direct application to the field as early as 1870, and several of the phosphate mining concerns then operating at Charleston advertised the material for sale. Chazal[3] states that some correspondence of Prof. Charles U. Shepard shows that the latter advised the use of

[1] Unpublished work.
[2] Phosphate Rocks of South Carolina, pp. 45–46 (1870).
[3] A Sketch of the South Carolina Phosphate Industry (1904).

the Ashley phosphates in lieu of bones as far back as 1860. A number of years later (1889), when the Florida hard rock phosphate fields were discovered, a considerable tonnage of soft phosphate (consisting chiefly of aluminum phosphate), which is found associated with the hard rock, was used locally by the farmers, and in a good many instances with reported success.

Some early adverse reports on the agricultural value of raw rock phosphate, coupled with the rapid establishing of plants for the manufacture of the more soluble and undoubtedly more quickly acting superphosphate, led to the practical cessation of use of this raw material in the South, and, while spasmodic efforts have been made to revive its use, it is generally believed that the more soluble phosphates are better adapted to most of the soils and crops of the South Atlantic States.

The first recorded work with raw rock phosphate was published by the Pennsylvania Experiment Station in 1885,[1] and consisted of two experiments (one field and one box experiment) begun in 1883. The box experiment was continued for two years only, but the field experiment was conducted through a period of thirteen years.

The Louisiana station was the next to report the results of experiments with this material, publishing in 1886[2] the yields of corn and oats obtained in several tests conducted for periods of one to two years.

Some years later this same station undertook a number of long-time experiments with raw rock phosphate, the results of which are recorded and discussed elsewhere in this bulletin.

Several other experiment stations (Florida, Connecticut, Georgia, and South Carolina) shortly afterward undertook some experiments with raw phosphates, and these have been followed by practically all the State stations east of the Mississippi River and a few of those west. The results obtained by the stations are discussed in detail further on.

THEORETICAL CONSIDERATIONS.

The fact that most deposits of amorphous phosphates are of organic origin led many to believe that this material when ground and applied directly to the soil would give results approximating those obtained from the use of nitrogenous guanos or ground bone.

A brief consideration of the manner in which deposits of rock phosphate are usually formed will show that it can not ordinarily be expected to yield its phosphoric acid as rapidly to the soil solution as the organic phosphates which have not undergone complete decomposition.

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[1] Pa. Agr. Expt. Sta., Ann. Rept. for 1884 (1885).

[2] La. Agr. Expt. Sta., Buls. Nos. 3, 4, and 6 (1886).

Some phosphate deposits, such as those found on islands of the Pacific and Indian Oceans, have resulted from the replacement of the carbonic acid in lime rock by phosphoric acid derived from overlying layers of organic material, usually the droppings of sea birds. The percentage of phosphoric acid in such excrements is quite high and is readily leached out by rain water, but the underlying coral limestone, of which such islands are often formed, takes up and fixes the phosphoric acid, forming relatively insoluble phosphate of lime.

Other phosphate deposits such as the brown-rock deposits of Tennessee are derived from phosphatic limestones by the leaching out of the more soluble carbonate of lime. The residue then consists of a porous rock containing a much higher percentage of phosphoric acid than the original material but in the form of the same relatively insoluble phosphate of lime.

While the origin of numerous deposits of phosphate is not altogether clear, in nearly every instance the nature of the rock is such that it is relatively insoluble in water and quite resistant to weathering influences. A quick response from applications of such material, therefore, is hardly to be expected unless it is either subjected to some chemical treatment by which the solubility of the phosphoric acid is considerably increased or it is mechanically ground to an impalpable powder and thoroughly distributed in the soil in such large quantities that an enormous surface of the mineral is exposed to the action of the soil waters.

In order to render the phosphoric acid soluble and facilitate its distribution in the soil, Liebig proposed to treat bones with sulphuric acid. When the nature of phosphate rock was established, Lawes applied the same treatment to that material, taking out a patent on his process in 1842. Since that date the use of acidulated phosphates has grown rapidly until now the vast bulk of the rock phosphate entering into the fertilizer industry is treated with sulphuric acid and manufactured into superphosphate.

Because ground raw rock phosphate has in many cases proved more effective on soils rich in organic matter, it is popularly supposed that certain organic acids in the soil exert a solvent influence on the rock similar to the effect produced by sulphuric acid.

The existence of such organic acids in the soil in quantities sufficient to affect appreciably the solubility of phosphate rock is very doubtful, but soils of high organic content are always rich in carbon dioxide and bacteria, both of which have an important influence on the solubility and alteration of soil minerals, and hence it is reasonable to expect an increase in the solubility of the phosphate contained therein over that of soils of low organic content. Some of the best field results with raw rock phosphate have been obtained where the material has been used in connection with stable manure or turned

under with a green crop. Either of these treatments increases both the bacterial growth and the amount of carbon dioxide in the soil.

On the other hand, highly productive soils not particularly rich in organic matter and which have never been fertilized contain much of their phosphoric acid as apatite or in some relatively insoluble form. Limestone soils high in phosphate, such as those in the Bluegrass Regions of Kentucky or in the Central Basin of Tennessee, continue to yield large crops without the addition of any soluble phosphate, and frequently do not respond to such applications.[1]

Burlison,[2] in a series of pot tests in pure sand, showed that farm crops were able to utilize the phosphoric acid of rock phosphate without the aid of organic material and that the yields were greater when the applications of rock phosphate were increased.

Other things being favorable, therefore, it seems reasonable to expect a soil low in phosphoric acid to respond to the addition of ground raw rock phosphate provided that the material is very finely ground, applied liberally, and thoroughly distributed through the soil by cultivation.

METHODS OF STUDYING THE SUBJECT.

In efforts to determine the fertilizer value of raw rock phosphate three general lines of investigation have been followed, namely, laboratory work, pot or greenhouse tests, and field experiments. The last named of these methods is by far the most important and the only one of much value, taken by itself. The other lines of work, however, are useful supplements to field experiments, and their importance should not be minimized.

LABORATORY WORK.

Laboratory work on ground raw rock phosphate divides itself into the following investigations:

1. Determination of composition of rock.
2. Methods of determining availability of phosphate.
3. Effect of degree of fineness of the phosphate on its solubility or availability.
4. Effect of organic fermentation on the solubility or availability of the phosphate.

COMPOSITION OF ROCK.

While phosphate rock from various sources differs considerably in composition and grade,[3] the bulk of the phosphoric acid contained

[1] Mooers, C. A., Tenn. Agr. Expt. Sta., Bul. 86, pp. 43–44, and p. 86 (1909).

[2] Mineral Phosphates and Plant Nutrition, Jour. Agr. Research, 6, No. 13, 485–514 (1916).

[3] Bureau of Soils, Buls. Nos. 69. 76, and 81; U. S. Dept. of Agriculture Buls. Nos. 14 and 312.

therein is combined with lime in the proportion to form tricalcium phosphate ($Ca_3(PO_4)_2$). Since this material in its natural state is rather sparingly soluble in water and very weak acid solutions, there may be little difference in the amount of phosphoric acid which the various grades of rock will yield to a definite quantity of such solvents within a limited time, provided the rock samples are ground to the same degree of fineness.

There has accumulated, however, considerable data, indicating that the availability of the amorphous phosphates is greater than that of apatite, and in a recent investigation Burlison[1] found that there was apparently quite a difference in the availability of rock phosphate from different sources when measured by crops grown in pots of small size.

The presence of such an impurity as limestone may have a considerable effect on the solubility of the phosphate in certain conventional solvents, since carbonate of lime is much more readily attacked by weak or dilute acid solutions and therefore tends to reduce their solvent power either by neutralization of the acid or by furnishing a common ion (Ca). A determination of the amount of free lime present may be of considerable importance if the availability of the phosphate is to be measured by its solubility in a conventional solvent.

Phosphates of iron and aluminum, while less soluble than the phosphates of lime, are not usually present in sufficient quantities materially to reduce the solubility of the rock. Unless, therefore, there is reason to suspect that these phosphates are present in abnormal amounts their determination is hardly deemed necessary.

The most important and often the only essential determination to be made in an analysis of phosphate rock for direct application to the field is its phosphoric-acid content. Nearly all rock is sold on the basis of the phosphoric acid which it contains and the degree of fineness to which it is ground.

METHODS OF DETERMINING AVAILABILITY OF PHOSPHATES.

The solubility of natural and manufactured phosphates in water and various media has been the subject of numerous investigations. practically all of which have been carried on with a view to obtaining an index of the availability of phosphates under soil conditions.

Deherain,[2] in attempting to determine the available plant food in soils, used a dilute solution of acetic acid. Gerlach[3] and Schloesing[4] employed aqueous solutions of carbon dioxide, on the theory that the natural soil waters owe their solvent action to this gas. The results

[1] Mineral Phosphates and Plant Nutrition, Jour. Agr. Research, 6, pp. 485–514 (1916).
[2] Ann. Agron., 17, 445 (1891).
[3] Landw. Vers.-Stat., 46, 201 (1896).
[4] Compt. Rend., 131, 149 (1900).

obtained by the latter investigator in determining the solubility of the calcium phosphate ($Ca_3(PO_4)_2,H_2O$) in carbonated waters and in water containing both calcium carbonate and carbon dioxide are given in Table I.

TABLE I.—*Solubility of lime phosphate in water containing carbon dioxide and calcium carbonate.*

Solvent.	Phosphoric acid (P_2O_5) per liter.	Lime (CaO) per liter.
	Mg.	*Mg.*
Water	0.74	
1,200 cubic centimeters distilled water and 50 cubic centimeters water saturated with CO_2	6.9	
1,000 cubic centimeters distilled water and 250 cubic centimeters water saturated with CO_2	48.5	
1,250 cubic centimeters water saturated with CO_2	91.9	
Water containing 174 milligrams $CaCO_3$ and 82 milligrams CO_2 per liter	.38	100.0
Water containing 290 milligrams $CaCO_3$ and 171 milligrams CO_2 per liter	1.1	162.3
Water containing 389 milligrams $CaCO_3$ and 270 milligrams CO_2 per liter	.80	218.8
Water containing 488 milligrams $CaCO_3$ and 415 milligrams CO_2 per liter	1.77	273.3
Water containing 558 milligrams $CaCO_3$ and 541 milligrams CO_2 per liter	1.30	312.7

It will be seen that the presence of carbon dioxide in water increases greatly the solubility of tricalcium phosphate, but that the addition of calcium carbonate depresses the solubility of the phosphate. This experiment was apparently conducted with samples of relatively pure materials, and no doubt the lime phosphate was in a precipitated form. Under such conditions a greater quantity of phosphoric acid (P_2O_5) would be dissolved than from the same quantity of natural rock phosphate.

An experiment to test the solvent power of carbonated waters on various phosphatic materials was conducted by Williams[1] many years before the one just cited. The results of this experiment are given in Table II.

TABLE II.—*Solubility in water of various phosphatic materials used as fertilizers.*

Source of phosphate.	Water required to dissolve one part of the phosphate.
	Parts.
Apatite from Perth, Canada, containing 89.27 per cent $Ca_3(PO_4)_2$	222,000
Same, levigated	140,000
Finely ground bone containing 56.78 per cent $Ca_3(PO_4)_2$	5,698
Same, calcined to burn out organic matter, 92.88 per cent $Ca_3(PO_4)_2$	8,029
Adulterated commercial bone dust containing 24.32 per cent organic and volatile matters and 35 per cent $Ca_3(PO_4)_2$	4,122
South Carolina phosphate containing 57.89 per cent $Ca_3(PO_4)_2$	6,983
Same, levigated	6,544
Guano containing 49.67 per cent $Ca_3(PO_4)_2$	8,009

[1] Chem. News, 24, 306 (1871).

It will be noted that the solubility of the amorphous phosphate (South Carolina rock) is considerably greater than the crystalline variety (apatite). Also that fine grinding increased the amount of the various materials dissolved.

Liebig,[1] Fleisher and Kissling,[2] Cameron and Hurst,[3] and Greaves[4] found that the presence of most fertilizer salts increased the solubility of phosphates of lime, and Cameron and Bell[5] showed that certain aqueous solutions increased the solubility of the various phosphates occurring in the soil.

Peterman[6] advocated an ammoniacal solution of ammonium citrate to determine the available phosphoric acid in soils. Emmerling[7] recommended a 1 per cent solution of oxalic acid to distinguish between lime phosphate and the phosphates of iron and aluminum. Hoffmeister[8] suggested an ammoniacal solution of "humic acid" for determining the various forms of phosphoric acid in soils. Fraps[9] determined the solubility of a number of soil phosphates in various strengths of hydrochloric and nitric acids as well as in 1 per cent citric acid, and tried to establish a relation between the chemically available phosphoric acid and that shown to be available by pot tests. While he found in several experiments that the order of availability as measured by N/5 nitric acid was the same as in pot tests, he also found that the difference in the feeding power of various crops and the nature of the soil influenced the degree of availability of soil phosphates. This experiment did not establish any standard for chemically available phosphoric acid in the soil. Stoddart[10] found that the digestion of 25 grams of soil with 250 cubic centimeters of N/5 nitric acid for five hours dissolved practically all of the lime phosphate but very little of the phosphates of iron and aluminum, and concluded that this test serves as an excellent indication of the amount of available phosphoric acid present in a soil. In the light of other experiments, however, the assumption that the phosphates of iron and aluminum are unavailable to crops is hardly justified.

Moore[11] attempted to find a strength of hydrochloric acid which would remove approximately the same amount of phosphoric acid from a soil as a crop of oats grown in pots. The conditions finally adopted for the extraction were to digest 200 grams of soil for five hours at a temperature of 40° C. with 1 liter of acid of such strength

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[1] Ann. Chem. Phar. **106**, 185 (1858).
[2] Bied. Centr., **12**, 155–161 (1883).
[3] Jour. Am. Chem. Soc., **24**, 885 (1904).
[4] Jour. Biol. Chem., **7**, 287–319 (1910).
[5] Bureau of Soils, U. S. Dept. of Agr., Bul. No. 41 (1907).
[6] Recherches de Chem. et Physiol., **3**, 50 (1898).
[7] Bied. Centr., **29**, 75 (1900).
[8] Landw. Vers.-Stat., **50**. 363 (1898).
[9] Jour. Am. Chem. Soc., **28**, 823–834 (1906).
[10] Wis. Agr. Expt. Sta., Research Bul. No. 2, pp. 50–60 (1909).
[11] Jour. Am. Chem. Soc., **24**, 79 (1902).

that it would be N/200 to methyl orange at the end of the digestion. This method, it is said, however, did not prove satisfactory where the soil had been fertilized. Hall and Plyman,[1] in an exhaustive article on the subject of "Available Plant Food in Soils," concluded, after trying numerous solvents on 19 different soils, that a 1 per cent solution of citric acid as recommended by Dyer[2] gives results more nearly showing the available plant food in soils. Dyer sought to determine the average acidity of the root sap, with a view to finding a natural solvent for plant food elements in the soil, and decided that a 1 per cent solution of citric acid most nearly approximated the average solvent power of the root sap. The theory, however, that the roots of plants excrete an acid (other than carbonic) which aids them in dissolving and securing their food has been practically abandoned. Kossowitch[3] concluded that the solvent action of plants on relatively insoluble phosphates is due to the carbon dioxide given off by the roots, but that plants are also able to supply themselves with phosphoric acid from extremely dilute solutions.

Hartwell[4] states that it is doubtful if any solvent will extract from all soils amounts of phosphorus bearing definite relations to those removed by even a given crop. The experiments of Ellett and Hill[5] bear out this statement. These investigators first fixed the phosphoric acid of superphosphate by means of the bases occurring in soils ($CaCO_3$, $Fe(OH)_3$ and $Al(OH)_3$), and then tested the solubility of the resulting phosphates in N/5 nitric acid, neutral ammonium citrate, and 1 per cent citric acid (Dyer's method). These solutions dissolved practically all of the phosphate of lime but only from 30 to 46 per cent of the iron and aluminum phosphates. When these phosphate compounds were mixed in pots with nearly pure sand, however, and wheat, oats, and corn grown therein, the pots treated with phosphates of iron and aluminum gave greater yields than those treated with phosphate of lime, showing that the availability as determined by the growing crops was the reverse of that shown by the conventional solvents.

The results obtained by Burlison[6] in a recent investigation agree in a general way with those of Ellett and Hill, since he found that the solubility of a mineral phosphate in a 0.2 per cent solution of citric acid bore no particular relation to its availability as determined by pot tests.

Hartwell[7] suggests that a better index of the available phosphoric acid in a soil might be gained by growing turnips therein and deter-

[1] Jour. Chem. Soc. Trans., **81**, 117–144 (1902).
[2] Jour. Chem. Soc. Trans., **65**, 115 (1894).
[3] Bied. Centr. **32**, 44–49 (1902).
[4] R. I. Agr. Expt. Sta., 18th Ann. Rept., p. 285 (1906).
[5] Va. Polytec. Inst., Agr. Expt. Sta., Ann. Rept. for 1909–10, pp. 44–65 (1911).
[6] Jour. Agr. Research, **6**, pp. 485–513 (1916).
[7] R. I. Agr. Expt. Sta., Bul. No. 154 (1913).

mining the phosphoric acid present in the roots. Analyses of turnips grown on soils treated with various forms of phosphoric acid showed that the percentage of P_2O_5 in the roots was fairly consistent with the availability of the phosphates as determined by crop yields.

In determining the trade value of fertilizer materials the Association of Official Agricultural Chemists[1] classes as available all phosphoric acid soluble in a neutral solution of ammonium citrate, and in the analyses of basic slag the association[2] has tentatively adopted Wagner's method, in which all phosphoric acid dissolved from a definite weight of the material by a certain volume of 2 per cent citric acid is considered available to crops.

Although several of these methods for determining the availability of phosphoric acid both in soils and fertilizers are useful in showing the relative solubility of various phosphates, nearly all of the processes so far suggested are empirical, and none of them are founded on a strictly scientific basis. While it has been demonstrated by actual field experiments that certain phosphates soluble in weak acids and dilute organic solutions are also active under soil conditions, in the light of both field and laboratory investigations all phosphatic materials which do not conform to these tests can not be classed as unavailable to crops. It must be remembered that the term "available" is a relative one. Practically every phosphate known is soluble to a certain extent even in pure water. The amount of phosphoric acid dissolved from the less soluble phosphates depends on the surface exposed, the quantity of solvent used, and the time of contact.

Raw rock phosphate conforms in part at least to practically all of the chemical availability tests, but its solubility in the various conventional media is materially affected by the three factors mentioned above. No method, therefore, which calls for contact for a limited time and the use of a definite quantity of relatively weak solvent, and does not state the degree of fineness to which the material should be ground, can show any sharp distinction between the amounts of phosphate available and unavailable under the conditions obtained in the soil.

EFFECT OF FINENESS OF GRINDING.

The fineness to which phosphate rock is ground undoubtedly has a very important influence on its availability to crops. Not only is it easier to distribute more uniformly the finely ground rock through the soil, but the immense amount of surface exposed by such material enables the soil water to dissolve a much greater proportion in a given time than where the rock is in relatively coarse particles.

[1] Jour. Assoc. Official Agr. Chemists, 1, No. 4, 4–5 (1916).
[2] Idem., pp. 14–15.

As early as 1868, Voelcker[1] recognized the importance of fine grinding in facilitating the solubility of bones, but considered unacidulated coprolites and apatite practically valueless to crops. Jordon[2] found in some greenhouse work (which is discussed elsewhere in this bulletin) that pots of quartz sand treated with "floats" produced greater yields of peas, barley, and rape than those receiving the same amount of phosphate in somewhat coarser particles. Burlison[3] in a similar experiment with 60-day oats employed Tennessee brown-rock phosphate of three different degrees of fineness in a series of pots containing relatively pure sand, to which were added also the other fertilizer elements. The results of this experithese experiments are given in Table IV.

TABLE III.—*Relation of size of particles of the availability of the phosphoric acid contained therein, as measured by 60-day oats.*

Pot number.	Phosphate added.	Degree of fineness.	Grain.	Straw.
	Grams.		*Grams.*	*Grams.*
17	2.6	80 to 100 mesh	5.9	6.8
18	2.6	do	7.0	10.1
19	2.6	100 to 200 mesh	5.8	11.1
20	2.6	do	7.7	11.4
21	2.6	200 mesh and finer	8.7	11.1
22	2.6	do	7.2	13.2

Table III shows that there was considerable difference between the average yields of oats treated with the coarser and those receiving applications of the more finely ground phosphate rock.

While the value of the conventional availability tests is seriously questioned, the solvents employed serve fairly well to determine the effect of fine grinding on the solubility of a given phosphate. In the following experiments two of the most widely used phosphates produced in this country, namely, the pebble phosphate of Florida and the brown-rock phosphate of Tennessee, were employed.

Samples of these types of rock were ground to three different degrees of fineness, as follows: (1) Between 60 and 130 mesh, (2) between 130 and 180 mesh, and (3) 180 mesh and finer. The solubility of the three grades of each type was then determined according to the official method of the American Association of Official Agricultural Chemists (solubility in ammonium citrate), according to Wagner's method (solubility in 2 per cent citric acid), and according to Dyer's method (solubility in 1 per cent citric acid). In addition to these conventional determinations the solubility of the material in water saturated with carbon dioxide was determined. The results of these experiments are given in Table IV.

[1] Jour. Royal Agr. Soc. 4, 176–196 (1868).
[2] N. Y. Agr. Expt. Sta. (Geneva), Bul. No. 358 (1913).
[3] Jour. Agr. Research, 6, pp. 507–508 (1916).

TABLE IV.—*Influence of fine grinding on the solubility of Florida and Tennessee phosphates in certain conventional solvents.*

[Analyses by R. F. Gardiner and J. A. Cullen.]

Type of rock.	Degree of fineness.	Total P_2O_5.	Percentage of total P_2O_5 soluble according to— Official method.	Wagner's method.	Dyer's method.[1]	Amount dissolved by water saturated with CO_2.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*P. P. M.*
Florida pebble	Between 60 and 130 mesh	35.53	2.76	11.54	2.55	2.0
Do	Between 130 and 180 mesh	36.27	4.66	16.10	2.59	3.0
Do	180 mesh and finer	37.03	5.54	18.66	2.57	4.0
Tennessee brown rock	Between 60 and 130 mesh	31.25	.83	8.16	2.51	2.0
Do	Between 130 and 180 mesh	29.96	2.34	8.85	2.62	4.0
Do	180 mesh and finer	26.80	3.80	17.60	3.11	4.5

[1] The solubility determinations according to Dyer's method were made on new samples.

Table IV shows that in nearly every instance the finest ground material yielded considerably more phosphoric acid to the solvents employed than the coarser material.

Several concerns now producing ground phosphate rock claim that their product is ground so that 80 per cent will pass a sieve of 200 meshes to the linear inch. While some tests run in this laboratory seem to make it doubtful if a uniform product of this degree of fineness can be placed on the market at present prices, the material should at least be ground so that 90 per cent will pass a 100-mesh sieve. Such rock will contain a large percentage of very much finer material.

EFFECT OF ORGANIC FERMENTATION.

It is generally believed by those who favor the use of raw rock phosphate as a fertilizer that the action of decaying organic matter increases the availability or effectiveness of the phosphate in the soil. While actual field experiments lend support to this conclusion, efforts to prove this point in the laboratory have not been altogether satisfactory.

Lupton[1] mixed floats with cottonseed meal and allowed the mixture to ferment. Citrate-soluble phosphoric acid was determined at the beginning and from time to time during the three months of the experiment. The results were inconclusive. McDowell[2] allowed a mixture of floats and manure to ferment in a barrel for 13 months and compared the water-soluble and citrate-soluble phosphoric acid present at the beginning and at the end of that period. No increase in the amount of citrate-soluble phosphoric acid was noted. In a similar experiment Holdefleiss[3] found but little increase in the citrate solubility of phosphate rock which had been mixed with various organic materials and inorganic salts and allowed to ferment

[1] Ala. Agr. Expt. Sta., Bul. No. 48, pp. 1–10 (1893).
[2] Pa. Agr. Expt. Sta., Ann. Rept. 1907–8, p. 175.
[3] Heiden, Dungerlehre, 2, 509.

for eight months. Pfeiffer and Thurmann[1] found that the composting of decaying organic matter and phosphates produced but a slight increase in the citrate solubility of phosphate rock and actually decreased the solubility of acid phosphate.

Truog,[2] however, states that these experiments are open to criticism, since no blanks or checks (P_2O_5 determinations) were run on the organic materials mixed or composted with the phosphates. This author carried on a number of laboratory experiments to study the effect of decomposing organic matter on the solubility of finely ground rock phosphate. This solubility, however, was determined in nearly every instance in a 0.2 per cent solution of citric acid, which can not be considered a proof of, nor necessarily an index to, the availability of the phosphatic material.

In his first experiment Truog made up the following mixtures in 1-gallon glazed jars, each provided with a hole in the bottom:

No. 1: 2.7 kilograms sand, 25 grams floats.
No. 2: 2.7 kilograms sand, 25 grams floats, 300 grams grass.
No. 3: 2.7 kilograms sand, 300 grams grass.
No. 4: 2.7 kilograms sand, 26 grams floats, 300 grams manure.
No. 5: 2.7 kilograms sand, 300 grams manure.

The sand used in this experiment analyzed 97.9 per cent silica; the floats consisted of a high-grade finely ground rock phosphate containing 34 per cent phosphoric acid (P_2O_5). The grass was fresh fine grass finely chopped, and the manure was fresh cow dung without any litter.

The contents of each jar were thoroughly mixed and an optimum amount of water was maintained in the jars for a little over four months. Both the water-soluble and citric-soluble phosphoric acid present in the mixtures were then determined. The results of these analyses are given in Table V.

TABLE V.—*Parts of phosphoric acid (P_2O_5) per million parts of the extracting solution.*

Jar No.	Treatment.	P_2O_5 extracted from jars by 3 liters of distilled water.	P_2O_5 extracted from 150 grams of material by 300 cubic centimeters of 0.2 per cent citric acid in 24 hours.	P_2O_5 extracted from 150 grams of material by 300 cubic centimeters of 0.2 per cent citric acid in 8 days.	P_2O_5 extracted from 60 grams of materia[l] by 1 per cant NaOH
		P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*
1	Quartz and floats	1.5	116.0	149.0	7.5
2	Quartz, floats, and grass	88.0	68.5	99.0	11.0
3	Quartz and grass	88.0	26.0	32.0	8.7
4	Quartz, floats, and manure	71.0	88.0	118.0	12.5
5	Quartz and manure	67.0	66.5	57.0	9.3

[1] Landw. Vers-Stat., 343 (1896).
[2] Wis. Agr. Expt. Sta., Research Bul. No. 20 (1912).

The fermentation of organic matter apparently had little or no effect on the solubility of finely ground rock phosphate in water and a depressing effect on its solubility in 0.2 per cent citric acid solution. In regard to the rock's solubility in 1 per cent sodium hydroxide solution, however, this depression is not so marked if indeed there is any. This investigation included a number of other interesting experiments, showing the solvent effect of carbon dioxide on natural phosphates and the great increase in the quantity of this gas in soils treated with manure. The pot work with raw rock phosphate conducted by Truog is discussed elsewhere in this bulletin.

In summing up the results of his work Truog concludes that the "solubility of phosphate as measured by a solvent like 0.2 per cent citric acid may be very different from the availability as measured by a growing crop." He thinks that the rôle which organic matter plays in rendering raw phosphates more available in the field is due to the increased quantity of carbon dioxide resulting from organic decomposition and the better distribution of the phosphate which is brought about by mixing it intimately with the organic material.

Sackett, Patten, and Brown[1] in an investigation on the solvent action of soil bacteria upon the insoluble phosphoric acid of bone and raw rock phosphate found that certain types of soil bacteria have the power of converting small quantities of insoluble phosphates into soluble form independent of acid formation, but that when bacterial growth is accompanied by the formation of acid the amount of phosphate dissolved is considerably greater.

Tottingham[2] found, however, that in mixtures of rock phosphate and manure both the water-soluble and citrate-soluble phosphoric acid were reduced by fermentation.

In a later and more exhaustive investigation Tottingham and Hoffman[3] showed that the action of fermenting manure on natural phosphates is much more complex than was formerly supposed. These investigators claimed that the decreased solubility of the phosphates in such mixtures was due to the fixing or absorption of the phosphorus by the manure organisms, but that the availability of the phosphorus in the cells of such organisms as measured by a growing crop (pot test) was as great as that in acid phosphate. Moreover, after fermentation has practically ceased the absorbed or altered phosphate is released in forms soluble in carbonated waters. The final conclusions reached in this investigation were that advantageous results are obtained by composting rock phosphate with fermenting manure, but that it is inadvisable to practice the same scheme with acid phosphate.

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[1] Mich. Agr. Expt. Sta., Bul. No. 43 (special), (1908).
[2] Science (n. s.) 35, 390 (1912).
[3] Wis. Agr. Expt. Sta. Research Bul. No. 29, pp. 273–321 (1913).

Forbes and Fritz[1] suggested the introduction of floats into the silo in order that the fermentation process and the subsequent passing of the ensilage through the animal's body would aid in rendering the rock phosphate more soluble. The following table gives a summary of the analytical results obtained by these investigators.

TABLE VI.—*Phosphorus in silage corn with and without added floats, and in silage made therefrom.*

Material.	Average content of phosphorus on water-free basis.				
	Total.	Water soluble.	Citrate soluble.	Soluble in 0.2 per cent HCl.	Water soluble plus citrate soluble.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Untreated green silage corn	0.207	0.149	0.021	0.083	0.170
Silage from untreated corn	.224	.160	.008	.111	.168
Green silage corn plus floats	.371	.136	.061	.172	.197
Silage from treated corn	.384	.157	.060	.237	.217

If the total quantity of phosphoric acid in the material is considered, it will be seen that the fermentation process actually decreased the percentage of water-soluble plus citrate-soluble phosphoric acid present in the silage corn. Fermentation also produced little or no effect on the citrate solubility of floats mixed and charged to the silo with the corn. The amount of phosphate dissolved by a 0.2 per cent solution of hydrochloric acid, however, was considerably increased by the ensilage process. If this were an index of availability (an assumption which is hardly warranted) the mixing of phosphate rock with ensilage might be considered good practice.

Mooers,[2] however, carried this investigation somewhat further and actually determined the citric-soluble phosphate in the dung of animals fed with ensilage treated with floats, comparing the results with the dung of similar animals fed with untreated ensilage.

The treated ensilage was produced by charging the silo with finely ground rock phosphate and corn at the rate of 2 pounds of the former to 100 pounds of the corn. It was assumed that the increased amount of total phosphoric acid in the dung of the animals fed with the treated ensilage was due to the rock phosphate in the ensilage. In order to have a check on the effect of fermentation and the subsequent digestive process on the solubility of the phosphate, an amount of rock phosphate equal to that in the dung produced from the treated ensilage was added to the dung produced from untreated ensilage. The results of this investigation are summarized in Table VII.

[1] Jour. Ind and Eng. Chem., 6, 222 (1914).
[2] Jour. Ind. and Eng. Chem., 6, 487–8 (1914).

TABLE VII.—*Phosphoric acid (P_2O_5) voided in dung of animals fed with phosphated and unphosphated ensilage.*

Material.	Phosphoric acid found.	
	Total.	Soluble in 0.1 per cent citric acid.
	Per cent.	*Per cent.*
Dung from cow No. 10 (untreated ensilage)	1.17	0.76
Dung from cow No. 10 (untreated ensilage) plus a quantity of floats equal to that in the dung from cow No. 30 fed with treated ensilage	5.95	.88
Dung from cow No. 30 (phosphated ensilage)	5.95	1.05
Dung from fawn heifer (untreated ensilage)	1.78	1.38
Dung from fawn heifer (untreated ensilage) plus a quantity of floats equal to that in the dung from the blue heifer fed with phosphated ensilage	9.34	1.47
Dung from blue heifer (phosphated ensilage)	9.34	1.86

Apparently the combined processes of fermentation and subsequent digestion of the phosphated ensilage produced small increases in the citric solubility of the rock phosphate, but in view of the fact that the animals would eat but limited quantities of the treated ensilage, and that it was doubtful whether the increase in solubility was due to the ensilage process or to animal digestion, he concluded that this method did not offer a practical means of rendering the phosphoric acid of raw rock phosphate available for agricultural purposes.

In a laboratory investigation on the effect of phosphates and sulphates on soil bacteria Fred and Hart[1] found that the addition of such materials to a soil in soluble form increased the ammonification, carbon dioxide evolution, and total number of bacteria. While these effects were much less marked in the case of a relatively insoluble phosphate (bone ash), the suggestion that the increase in yield resulting from phosphate applications is due in part to the promotion of bacterial activity, which in turn increases ammonification (or the supply of available nitrogen) and also the carbon dioxide content of the soil, seems reasonable. The latter compound is effective in bringing about the solution of a further quantity of phosphate mineral.

Hopkins and Whiting,[2] in an article entitled "Soil Bacteria and Phosphates," showed that nitrous acid produced by the action of nitrate bacteria upon ammonium salts dissolved phosphate of lime, the amounts of lime and phosphoric acid in solution increasing as the quantity of oxidized nitrogen increased. These same authors also point out that if all the nitrogen required by standard crops were obtained from the oxidation of ammonia or ammonium salts and the acid thus produced made to act upon rock phosphate the

[1] Wis. Agr. Expt. Sta. Research Bul. No. 35, pp. 35–66 (1915).
[2] Ill. Agr. Expt. Sta., Bul 190, pp. 395–406 (1916).

amounts of phosphoric acid and lime thus rendered water soluble would be many times greater than required by these same crops.

Nearly all the experiments so far considered for determining the effect of decaying organic matter upon rock phosphate have depended on some weak solution (usually an acid) to measure the availability of the phosphate thus treated. Truog's conclusion that the conventional laboratory methods for measuring the availability of phosphates are unsuitable under certain conditions seems quite logical. Take, for instance, the fermentation of manure, which results in the formation of alkaline products, which predominate for a time at least over the acid products. There seems little reason to suppose that changes in raw rock phosphate brought about by such fermentation can be measured by the solubility of the phosphate in acid solution.

It is true that after the fermentation has proceeded further and the alkaline products have been largely evolved or neutralized, or after fermentation has ceased and the altered phosphate has been released by the death of the organisms which absorbed it into their cells, one might expect that the solubility of the phosphate in water saturated with carbon dioxide would be an index to its availability. But while carbon dioxide increases quite appreciably the solubility of the difficultly soluble phosphates, this effect is limited at any one time by the amount of the gas which can enter into solution. During the growing season, however, the constant absorption of the dissolved phosphate by plant roots allows the carbon dioxide to act continually upon more phosphatic material. Decaying organic matter in contact with raw phosphate, therefore, should be furnishing carbon dioxide sufficient to keep a fairly constant supply of phosphoric acid in the soil solution, and therefore the availability of the phosphate should be considerably increased by its presence.

POT AND GREENHOUSE WORK.

The main advantage of pot work in testing out fertilizer materials lies in the fact that the conditions under which the experiments are conducted can be to a large extent controlled.

Soil in the same mechanical condition and of the same chemical composition can be obtained for a series of pots with little difficulty. Uniform conditions of moisture and temperature can be maintained throughout the growing period, and such disturbing factors as blight, insect pests, and injuries from heavy rain, hail, or high winds can be reduced to a minimum.

On the other hand, the slightest variation in the conditions of the experiment may produce such differences in the crops as to lead to very erroneous conclusions. Careful selection of seed, uniform pack-

ing of the soil to insure equality in drainage, and a thorough distribution of the fertilizer material are essential in order to obtain reliable data from pot tests.

Another disadvantage in pot work lies in the fact that it is difficult to grow many plants to maturity in pots because of the limited space in which the root systems have to expand and forage.

While pot tests with fertilizer materials are valuable for preliminary experiments and are also useful supplements to field work, the results obtained therefrom can not be regarded as final proof of the value of the fertilizer material under investigation. In fact, pot tests do not necessarily serve as an index to the results which will be obtained in the field.

The amount of pot or greenhouse work on ground raw rock phosphate is comparatively small. What has been done is discussed further on in the detailed descriptions of the work of the State experiment stations.

FIELD EXPERIMENTS.

The final proof of the value of a fertilizer material must rest upon field experiments, but field experiments, unless carefully conducted with due regard to the numerous factors influencing crop yields, are often worse than valueless.

Because of limited knowledge of these factors, the earlier agronomists had a tendency to publish the results of field work conducted for a year or two only and to draw conclusions from very meager data. Unfortunately, even now the results of field experiments are often published without at the same time reporting data or mentioning certain factors which would be a great aid in interpreting the significance of the crop yields. Moreover, the experiments (particularly raw rock phosphate tests) are conducted in such different ways and under such a variety of conditions that it is impossible to reduce them to a uniform basis for the sake of comparison. The desirability of having field investigators employ the same methods and a minimum standard in both variety and fertilizer experiments has been pointed out by Piper and Stevenson.[1]

In considering the results of field experiments with raw rock phosphate, careful attention should be given to the following factors:

1. Uniformity of experiment field.
2. Topography and drainage conditions.
3. Physical and chemical composition of the soil.
4. Previous treatment of field.
5. Climatic conditions.
6. Injuries from disease, insects, and animals.

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[1] Standardization of Field Experimental Methods in Agronomy. Proc. Am. Soc. Agron., 2, 70–76 (1910).

7. Kind of crops grown and selection of seed.
8. Rate of application and uniform distribution of phosphates.
9. Methods of comparing raw rock with other phosphates.
10. Effect of other fertilizers.
11. Number and distribution of plots.
12. Duration of experiment.

UNIFORMITY OF EXPERIMENTAL FIELD.

The greatest care should be exercised in selecting a field containing soil of a uniform character throughout, for unless the soil on the various plots has the same productive power or the probable difference in its natural fertility on these plots is determined, the yields obtained from the application of fertilizers may have little or no meaning. A soil survey of a field is of great importance, but such a survey unless supplemented by borings may not give sufficient information, since an apparently uniform soil may so vary in depth from place to place as to cause wide differences in the productivity of the various plots. Hall and Russell[1] state that a simple yet sensitive method of determining the uniformity of a soil consists in ascertaining the percentage of moisture in samples collected from various parts of a field at the same time to the same depth. An even more sensitive test, it is said, consists in determining the percentage of nitrates in such samples.

Piper and Stevenson[2] state that it is difficult to say what is the ordinary error due to soil inequality. Hall and Russell[3] state that the Rothamsted records show that there is an error of 10 per cent on plots where the past treatment has been uniform and general conditions were favorable for experimental work.

In conducting fertilizer experiments in the field attempts have been made to determine the so-called "natural fertility" of the plots subsequently treated with fertilizers. Offhand the most logical method appears to be to complete at least one rotation of the system to be employed during the experiment without the addition of any fertilizer whatever. The usefulness of this method of valuing the plots, however, appears very doubtful. In fact, it might well be asked, "Is there such a thing as natural fertility under field conditions when these conditions vary so greatly from year to year?" Lyon[4] has shown that when corn, oats, and wheat were grown for several years on the same fields no definite relation was shown between the yields of the various plots from year to year.

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[1] Chem. News, **102**, 180 (1910).

[2] Standardization of Field Experimental Methods. Proc. Am. Soc. Agron., **2**, 70–76 (1910).

[3] Error of Experiment in Agricultural Field Tests. Chem. News, **102**, 80 (1910).

[4] Experiments to Estimate Errors in Field Plat Tests. Jour. Am. Soc. Agron., **3**, 89–114 (1911).

Where the check plots and those receiving various fertilizer treatments are replicated several times throughout the experiment field, absolute uniformity in a field is not so essential. This point, however, is discussed under the heading "Number and Distribution of Plots."

TOPOGRAPHY AND DRAINAGE CONDITIONS.

The soil of an experiment field may be fairly uniform throughout, but unless the topography and drainage conditions are regular, certain parts of the field will be more productive than others. Drainage, whether natural or artificial, is seldom uniform on a field.[1] If a soil has good underdrainage, but the topography of the field is not regular, the accumulation of silt and the greater moisture content of the low ground will probably render these depressions more productive than the high ground. On the other hand, if the low ground is poorly drained, excessive moisture in the spring may keep the ground cold, delaying greatly the growth of the crop, preventing aeration of the soil, and hindering the development of root systems sufficiently extensive to keep the crop from suffering from droughts encountered later in the year.

Topographic irregularities may also affect crop yields by causing certain parts of a field to be shaded more than others. The shaded areas may or may not produce greater yields than the unshaded, depending on the climatic conditions and the crops grown.

Since it is frequently not practicable to obtain an experiment field free from topographic irregularities, the plots should be laid off or distributed in such a way that these irregularities are apportioned (as nearly as possible) equally among the various treatments.

PHYSICAL AND CHEMICAL COMPOSITION OF SOILS.

Fertilizers affect various soil types and soils varying in chemical composition quite differently. Very sandy soils, low in organic matter, ordinarily respond quickly to the soluble fertilizers, but owing to their low absorptive capacity they may often be leached of their soluble salts during excessive rains. Clay soils, on the other hand, if kept in good tilth, have a great absorptive capacity, but often do not respond so readily to fertilizer treatment until they have been heavily limed. Soils rich in organic matter usually respond more quickly to the relatively insoluble fertilizers than those of low organic content, but here again the soil type and its mineral constitutents are factors which must be considered.

The digestion of a soil with hydrochloric or nitric acid of various strengths is of little value as an index to its fertility or to its content

[1] Hall, A. D., and Russell, E. J. Chem. News, 102, 180 (1910).

of available plant food, but the determination of the total quantities of the fertilizer elements (by fusion with sodium carbonate) is frequently of considerable importance, particularly if supplemented by a mineralogical examination.

Some soils high in phosphoric acid seem little affected by applications of phosphatic fertilizers, while in other soils the lack of phosphoric acid appears to be the factor limiting their fertility.

PREVIOUS TREATMENT OF FIELD.

If a soil is to be tested to determine its responsiveness to a phosphatic fertilizer, it is obvious that it should not have been treated with phosphates a short time before the experiment. Again, unless the experiment is undertaken primarily to show how a badly managed soil may be restored to former fertility, care should be taken that the soil is not in a "run-down" condition, due to improper handling and cropping. Ordinarily a field should be selected on which the soil is in a condition as nearly as possible like its original state.

Since most of our cleared land has been cultivated and much of it fertilized, it is not often possible to obtain a field which is immediately available for experimental purposes. It is often well, therefore, to allow a field to lie fallow for a year or so before using it for plot work in order that the effect of previous treatments may be reduced to a minimum. In any event the history of the field for a few years prior to the experiment should be recorded.

CLIMATIC CONDITIONS.

The temperature, rainfall, sunshine, wind, and to a large extent, blight, and insect pests are factors beyond control in field work.

Because of the early stimulation produced by a soluble fertilizer a late frost may cause more damage to plots thus treated than to those on which a less soluble fertilizer has been used. On the other hand, early stimulation and the quick maturity of certain crops are almost essential in some of our Northern States in order that they may be harvested before the early frost.

High winds or hailstorms may also cause more damage to the better-developed crop than to that which is backward for lack of fertilizer. If such a factor is not considered the final results may lead to very erroneous conclusions. Excessive rains will sometimes leach a soluble fertilizer out of a sandy soil so quickly that its full effect will not be felt and the less soluble fertilizers will appear to greater advantage. On the other hand, the early stimulation produced on a plot by a soluble fertilizer may later enable the plants to resist a severe drought more effectully than those on a plot which has been treated with a less soluble fertilizer.

INJURIES FROM DISEASE, INSECTS, AND ANIMALS.

Injuries from disease, insects, and animals are sometimes so great as completely to destroy the value of a year's work. The relative damage to certain plots frequently may be estimated and allowances made, but where the injury is considerable, it is often wise to throw out the results entirely. Hall and Russell[1] state that "the unequal incidence of disease is sometimes very troublesome." It is certainly rare if the various plots of an experiment field are equally affected by one or more of the above injuries; so, no matter how slight the damage may appear, it should be recorded and mention made of it in publishing the field results.

KIND OF CROP GROWN AND SELECTION OF SEED.

Experience has shown that for trucking purposes, where the delay of a week or less in the maturing of a crop will often mean the difference between profit and loss to a farmer, the water soluble fertilizers are much more desirable than the relatively insoluble varieties. Some crops also seem better able to utilize the less soluble phosphates than do other crops.[2] Extensive root systems may enable certain plants to forage for their food better than those which feed over a more limited area.

The selection of uniform seed is also an important factor, particularly when dealing with small plots. In order to decrease the probable variation in individual productiveness of corn grains, Lyon[3] suggested the plan of planting all the plots in an experiment with kernels from the same ears. While such a scheme is not possible in the case of many other crops, the selection of seed either by mechanical or other means can not be sufficiently emphasized.

UNIFORM DISTRIBUTION OF THE FERTILIZER.

In order to obtain the maximum benefit from an application of fertilizer a thorough distribution in the soil is necessary. The root systems of some plants are so extensive that they feed over a very wide range, and unless the fertilizer has affected the soil in the vicinity of all the root hairs, full benefit from the application can not be obtained. In the case of a soluble fertilizer it is not necessary to exercise such extreme care in application, since the distribution is largely brought about by rain and the circulation of the soil water, but with relatively insoluble fertilizers, such as basic slag,

[1] Error of Experiment in Agricultural Field Tests. Chem. News. **102**, 180 1910).

[2] Me. Agr. Expt. Sta. Ann. Rept. for 1898 (1899). R. I. Expt. Sta., Bul., 163, p. 516–560 (1915).

[3] A Test of Planting Plots With the Same Ears of Corn to Secure Greater Uniformity in Yield. Proc. Am. Soc. Agron., 2, 35–37 (1910).

bone meal, and ground rock phosphates, the distribution must be brought about by mechanical means.

A brief consideration of the facts will show how important it is that applications of raw rock phosphate should be heavy in order that the material may have a fair trial.

An average soil contains 0.113 per cent of phosphoric acid (P_2O_5) or 1.98 tons per acre-foot. If such a soil has been given thorough cultivation for a number of years the phosphoric acid contained therein should be fairly well distributed, at least much better than it is possible to distribute a relatively small application of raw rock phosphate in a limited time by mechanical means. It hardly seems possible that such a soil could respond to applications of rock phosphate supplying an amount of phosphoric acid equivalent to only 1 or 2 per cent of that which it already contains in a form nearly if not quite as available. An application of 1,300 pounds per acre of average raw rock phosphate (30 per cent P_2O_5) would increase the quantity of phosphoric acid already present in an average soil approximately 10 per cent.

Hopkins[1] in his recommendations for soil treatment advises the use of raw rock phosphate on soils containing phosphoric acid in subnormal amounts at the rate of 1,000 pounds per acre every five or six years (preferably in connection with farm manure).

Truog[2] of the Wisconsin Experiment Station conducted a pot experiment in which he showed that where raw rock phosphate was very thoroughly mixed with ground quartz much better yields of corn and oats were obtained than where only ordinary care in mixing was practiced.

The use of applications of from 1,000 to 2,000 pounds of very finely ground raw rock phosphate every few years and the mixing of the same intimately with the soil by thorough cultivation should bring about the desired distribution. In this way a large surface of the relatively insoluble material is exposed to the action of the soil water, and much more of the phosphate can therefore be dissolved within a limited time.

METHODS OF COMPARING VARIOUS PHOSPHATES.

In nearly all of the field experiments so far conducted to compare the relative fertilizer values of ground raw rock phosphate and the more soluble phosphates, three general methods of application have been followed: (1) Equal weights of the various phosphatic materials have been applied, usually at a medium rate per acre. (2) The various phosphates have been added in such quantities as to furnish

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[1] Ill. Agr. Expt. Sta.. Bul. No. 123 (1908).
[2] Wis. Agr. Expt. Sta., Research Bul. No. 20, p. 42–45 (1912).

equal amounts of phosphoric acid to the soil, the applications usually being at a rate supplying phosphoric acid sufficient for one year's crop. (3) The several phosphates have been applied in quantities representing equal money values at the particular time and in the particular locality in which the experiment was conducted.

Unfortunately, the first method of comparison has been the one employed in many field experiments, and while the results obtained are of some value, the method is very illogical, both from a scientific and economic viewpoint, since there are wide differences in the phosphoric acid-content of the various phosphates and the cost of these phosphates differs greatly. The only points in favor of such a method of comparison are that the amount of labor expended in spreading equal quantities of phosphatic material is the same and that all experiments conducted according to this method are to a certain extent comparable.

If the rôle which the more soluble phosphates play in the soil was simply that of supplying plant food, and the cost of phosphoric acid in its various forms was practically the same, the second method of comparison would be the logical one to follow. Moreover, all experiments conducted according to this method are also to a certain extent comparable. But water-soluble phosphates perform other functions in the soil which are often as important as the direct supplying of plant food to the growing crop. Not only do they affect the solubility of the soil minerals, but they influence and stimulate bacterial life and alter the physical condition of the soil. Because of the ease with which they are distributed in the soil and the quantity of soluble sulphates with which they are usually associated (in acid phosphate), they can not but be more energetic in their action than equal amounts of phosphoric acid in the form of relatively insoluble phosphates, and therefore a comparison of the two classes of phosphates based on equal applications of phosphoric acid is almost certain to be favorable to the soluble variety, even though the cost of the less soluble phosphates is usually considerably less.

The third method of comparing the various classes of phosphates has much to recommend it, since the effectiveness of the insoluble phosphates must depend largely on their thorough distribution in the soil, a distribution which can only be brought about by heavy applications of very finely ground material. Moreover, the relative value of two fertilizer materials must in the end be determined by the financial returns obtained from equal investments in the two forms. In many localities the price per ton of finely ground raw rock phosphate is about one-half that of acid phosphate or basic slag and one-third that of bone meal. Since the average rock phosphate contains about twice as much phosphoric acid as acid phosphate, the same

amount of money will frequently purchase four times as much insoluble as soluble phosphoric acid.

Many experiments conducted according to this third plan, however, are not comparable since not only do the prices of the two forms of phosphoric acid vary considerably in different localities, depending on the distance to the mines and fertilizer factories, but the margin of difference also fluctuates from year to year, depending on market and labor conditions.

While this third method of comparison appears much fairer than the first and second, it is open to objections from a strictly business standpoint.

Practically all of the more ardent supporters of ground raw rock phosphate as a fertilizer concede that full benefit can not be gained from applications of such material until it has been allowed to remain in the soil for a year or more, and that it becomes increasingly effective as it becomes more thoroughly distributed through cultivation and is exposed to the action of certain soil solvents. This means the investment of capital which does not pay its full interest for some years, while an equal amount of money invested in acid phosphate may pay good interest the first year. The following plan, which does not yet seem to have been tried, appears to be a more logical method of comparing the two classes of phosphates:

Apply the first year the several phosphates in quantities representing equal money values. When the crops are harvested, any increase from the acid phosphate plots over and above that from the raw rock plots reinvest in acid phosphate to be applied to the next crop of the acid phosphate plot, thus keeping the net profit from the two plots constantly equal for a number of years until sufficient time has elapsed for the raw rock to have reached its maximum effectiveness.

Hopkins has proposed and followed a scheme somewhat similar to the above in the addition of manure or crop residues to variously treated plots. His plan consists in adding to each treated plot after the first year these materials in quantities equivalent to the amounts which would be produced from the crop grown on that particular plot.

In considering the field work of the experiment stations, discussion of the profits obtained from various fertilizer treatments have in most instances been omitted since the cost of fertilizer materials as well as most crops vary from year to year and place to place. It was thought best, therefore, to allow those sufficiently interested in the subject to figure the financial returns for any particular time and locality.

EFFECT OF OTHER FERTILIZERS.

It is maintained by many agricultural investigators that it is not possible to ascertain the phosphoric acid requirement of a soil and crop until nitrogen and potash have been supplied in optimum quantities. In other words, since these three fertilizer elements are taken up in a definite ratio by various crops, an adequate supply of any two elements must be present in the soil solution before the plants can utilize their full quota of the third. While this is to a certain extent true, the methods employed in bringing about this end by no means show conclusively that only the optimum quantities of the fertilizer elements are present. For instance, the application of potash to a soil until a crop no longer responds to further additions of this element simply means that there is a limit above which potash when applied alone gives no increase in yield. But potash may be present in the soil solution in far greater quantities than can be utilized by the plant. The excess over and above that required to grow a maximum crop may be performing any or all of several functions just as important as the direct supplying of plant food. Moreover, the addition of a phosphatic or nitrogenous fertilizer may entirely alter the function of the excess potash and will certainly affect the nutrient qualities of the soil solution and the feeding powers of the crop.

It has been pointed out by Cameron[1] that fertilizers not only affect the chemical composition of the soil by the actual addition of salts or organic compounds, but they alter the nature and solubility of the minerals already present. They also have an important influence on the physical condition of the soil, its bacterial content,[2] and upon other active biological agents which directly or indirectly affect plant growth.

One of the most conclusive proofs that the plant food theory is inadequate to explain entirely the action of fertilizers is the fact that stable manure, which is recognized generally as the most effective of all fertilizers, contains the three elements, nitrogen, phosphorus, and potassium, in quantities entirely insufficient to account for the increase in yields obtained from ordinary applications of this substance.

No matter which view is taken concerning the action of fertilizers, the conclusions are in a general way the same, i. e., the application of one fertilizer has an important influence on the action of another. In the case of raw rock phosphate it has been pointed out that most fertilizer salts exert a solvent effect upon this material, and therefore it is reasonable to expect its effectiveness to be somewhat in-

[1] The Soil Solution, pp. 105–109 (1911).
[2] Fred and Hart. Research Bul. No. 35, pp. 35–66, Wis. Expt. Station (1915).

creased where it is applied in conjunction with commercial forms of nitrogen and potash.

NUMBER AND DISTRIBUTION OF PLOTS.

It has been pointed out by various investigators that a very much clearer and more accurate knowledge of the value of fertilizer treatments can be gained by employing on a limited area many small plots, repeating each fertilizer treatment as well as the checks on several well distributed plots, than on the same area where larger plots but fewer duplicates are employed.

Piper and Stevenson[1] state that a long period of experimentation as well as the replication of plots tends to reduce probable error. Mercer and Hall[2] in summing up the results of an investigation on "Errors of Field Experiments," state that in field trials the error diminishes with increasing size of the plot, but the reduction in error is small when the plot is above one-fortieth acre. These authors recommend that in any field experiment each unit of comparison (variety, method of fertilizing, etc., according to the object of the experiment) should be given five plots of one-fortieth acre each, systematically distributed within the experimental area. Lyon[3] concludes that an area of one twenty-fifth acre of land, in four widely separated plots, devoted to any one test, secures a much greater degree of accuracy than the same area of land in one body. Olmstead[4] states that the replication of plots is a great satisfaction both to the experimenter and the readers of the literature, since it enables both to determine whether the results show any valid conclusions by giving them a means to estimate the precision of the work.

Whitney[5] states, "It is obvious that if the range of the yields of the different fertilizer plots among themselves is no greater than the range of the yields of the check plots among themselves, the relative effect of the different fertilizers would have no practical significance. Very rarely are there duplicates of any fertilizer treatment, and this is a weakness of the system. There are admittedly wide variations in the yield of check plots, and to determine the real yield under fertilization, it is just as important to have eight or ten duplicate fertilizer plots as it is to have that number of duplicate check plots."

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[1] Standardization of Field Experimental Methods in Agronomy. Proc. Am. Soc. Agron., 2, 72 (1910).

[2] Experimental Error of Field Trials. Jour. Agr. Sci., 4, pt. 2, 107–127 (1911).

[3] Experiments to Estimate Errors. Proc. Am. Soc. Agron., 3, 114 (1911).

[4] Some Applications of the Method of Least Squares to Agricultural Experiments. Jour. Am. Soc. Agron., 6, 202 (1914).

[5] Unpublished work.

DURATION OF EXPERIMENTS.

Because of the numerous conditions just discussed, some of which are beyond control and some of which vary in spite of the exercise of the greatest care, it is obviously unwise to draw conclusions from field experiments which have been conducted for a short time only. Climatic conditions vary so greatly from year to year that in order to gain an accurate knowledge of the value of a fertilizer material the same crop should be grown several times on the same land. Where proper systems of rotation are practiced it takes from 6 to 20 years to accomplish this end. In studying the effect of the less soluble fertilizers, time plays a very important part. Not only does the material often become more soluble, but it becomes more thoroughly distributed in the soil from year to year, and hence is more readily available to the root systems of crops.

RESULTS OF EXPERIMENTS.

ALABAMA.

No field experiments with raw rock phosphate continuing beyond three years have been conducted by the Alabama station. Two series of cooperative one-year experiments, however, were carried on, one in 1891,[1] consisting of 25, and the other in 1892,[2] consisting of 35 experiments. In these experiments equal amounts of acid phosphate and raw rock phosphate were compared but they were applied at a rate (240 to 300 pounds per acre) considerably below that at which the latter should prove effective. In these experiments the average yields of the acid phosphate plots were appreciably greater than those of the raw rock plots, though the latter showed considerable gains over the average of the checks.

A field experiment conducted for three years was reported by the Alabama station in 1913.[3] The general scheme and results of this experiment were in accord with those just mentioned, but the yield of the raw rock plot the third year was almost identical with that of the acid phosphate plot.

CONNECTICUT.

The work of the Connecticut station with raw ground rock phosphate has been very limited, none of the experiments having been conducted sufficiently long to warrant repetition in detail. An experiment began in 1887[4] and continued for three years[5] on the same

[1] Ala. Agr. Expt. Sta., Bul. No. 23 (1891).
[2] Ala. Agr. Expt. Sta., Bul. No. 34 (1892).
[3] Ala. Agr. Expt. Sta., Bul. No. 173, p. 139 (1913).
[4] Conn. Agr. Expt. Sta., Ann. Rept. for 1888, pp. 110–117 (1889).
[5] Conn. Agr. Expt. Sta., Ann. Rept. for 1889 (1890).

field was conducted for the purpose of comparing the effects of various phosphates on Indian corn.

The plots were treated with liberal applications of potash and nitrogen in readily available form and the various phosphates were applied in quantities representing (at that time) equal money values. During the second and third years of the experiment no further additions of phosphates were made, in order that their residual effects might be studied, but the applications of potash and nitrogen carriers were made each year. During the first year of the experiment the plot treated with acid phosphate showed to considerably greater advantage than those receiving raw ground South Carolina rock (560 pounds per acre), but in the second and third years (with no further additions of phosphates) the production of the acid-phosphate plot fell off, while that of the raw-rock plot increased to such an extent that it surpassed the yield obtained from the acid-phosphate plot during the first year of its application.

The results of 17 other short-time experiments, 15 of which were continued for only one year, were reported by the Connecticut station[1] between the years 1888 and 1895, but while most of these showed indications of beneficial results from the use of raw rock phosphate, the data given are too meager to warrant serious consideration.

While the results of the field work with raw rock phosphate so far presented by the Connecticut Experiment Station must be regarded as only indications at best, they are nevertheless favorable to the use of raw rock phosphate.

DELAWARE.

The only experiment with natural phosphates yet reported by the Delaware station was a pot test conducted by W. H. Bishop[2] in 1893 in which a study was made of the effects of various phosphates (in combination with potash and nitrogen carriers) on the yields of soy beans planted in three different types of soil.

Although the soluble phosphates led all the others, the short duration of this experiment (one year), the light applications of the relatively insoluble phosphates—applications which would add less than 0.007 per cent of P_2O_5 to a soil of medium texture—and the wide divergence in the yields of some of the check pots make these results hardly worthy of repetition.

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[1] Conn. Agr. Expt. Sta., 14th Ann. Rept., pp. 203–219 (1890); 19th Ann. Rept., pp. 122–127 (1895).

[2] Del. Agr. Expt. Sta., 6th Ann. Rept., pp. 193–202 (1893).

FLORIDA AND GEORGIA.

The Florida and Georgia State Experiment Stations have conducted no field experiments with ground raw rock[1] continuing beyond one year.

Because of the limited data given and the short duration of these experiments, their repetition is not justified.

ILLINOIS.

The Illinois Experiment Station recommends the use of ground raw rock phosphate as a fertilizer more strongly than any other station; in fact it is the only station which now advises the use of this material for general farming above any other phosphate carrier.

Hopkins first advocated the use of raw rock phosphate in 1903,[2] basing his recommendations on the work of the Ohio and Maryland stations. In most of the early published work of the Illinois station steamed bone meal was the phosphate carrier used,[3] though it is stated that on certain plots raw rock phosphate was substituted for the former. What plots these were, however, is not made clear.

In the summer of 1905[4] the results of some pot culture experiments conducted in order to compare the relative fertilizer values of raw rock phosphate and steamed bone meal were published.

The soil used was the gray silt loam of the Lower Illinois glaciation and wheat was the crop employed in the test. The pots were $10\frac{1}{2}$ inches in diameter, but their height and cubic capacity are not given. The author states that equal money values of the two phosphates were employed in this test, that is, three times as much raw rock phosphate was added as bone meal. While the actual rate of application per pot and per acre are not given, it is presumed that the rate was the same as for the field experiments, viz, 200 pounds steamed bone meal per acre per annum and 600 pounds of raw rock phosphate. In certain pots the phosphate was turned under with a good growth of clover, in others with manure, and in still others with both clover and manure. The results of this comparative test are given in Table VIII, the yields being expressed both in grams per pot and bushels per acre.

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[1] Fla. Agr. Expt. Sta., Bul. No. 3, pp. 3–6 (1888); Bul. No. 10, pp. 21–27 (1890); Bul. No. 13, pp. 9–15 (1891); Bul. No. 82, p. 397 (1905); Press Bulletin No. 77 (1908).
Ga. Agr. Expt. Sta., Bul. No. 2, pp. 35–37 (1889); Bul. No. 25 (1894); Bul. No. 26 (1894); Bul. No. 27 (1894).

[2] Ill. Agr. Expt. Sta., Circular No. 68, April, 1903.

[3] Ill. Agr. Expt. Sta., Bul. No. 99, March, 1905; Circular No. 96, July, 1905; Circular No. 97 (1905); Bul. No. 115 (1907).

[4] Ill. Agr. Expt. Sta., Circular No. 97 (1905).

TABLE VIII.—*Yields of wheat obtained in pot experiment to test the relative values of raw rock and steamed bone meal.*

Treatment.	Wheat yields.		Increase.
	Per pot.	Per acre.	Per acre.
	Grams.	*Bushels.*	*Bushels.*
None	10.0	27	....
Clover	16.3	43	16
Bone meal	14.7	39	12
Rock phosphate	14.2	38	11
Clover, bone meal	22.2	59	32
Clover, rock phosphate	23.3	62	35
Manure	16.5	44	17
Clover, manure	22.7	60	33
Manure, bone meal	19.4	52	25
Manure, rock phosphate	19.5	52	25
Clover, manure, bone meal	23.1	62	35
Clover, manure, rock phosphate	23.3	62	35
Potash	11.3	30	3
Clover, potash	18.4	49	22
Potash, bone meal	18.4	49	22
Potash, rock phosphate	18.2	49	22
Clover, potash, bone meal	21.9	58	31
Clover, potash, rock phosphate	21.9	58	31
Manure, potash	18.1	48	21
Clover, manure, potash	19.1	51	24
Manure, potash, bone meal	19.3	51	24
Manure, potash, rock phosphate	19.0	51	24
Clover, manure, potash, bone meal	25.3	67	40
Clover, manure, potash, rock phosphate	25.3	67	40
None	10.6	28	....

The beneficial effects of phosphate in this particular experiment are quite marked, even though the test was of comparatively short duration. The results obtained seem to indicate that raw rock phosphate (an equal money value) may be substituted for bone meal, particularly if the phosphate is applied with manure or turned under with a leguminous crop. In practically every instance the raw-rock pots equaled or surpassed the bone-meal pots with which they were directly comparable.

A number of papers by Hopkins [1] on the use of raw rock phosphate as a fertilizer appeared in 1908 and 1909, but the field work of the Illinois Station described in several of them is given more fully in subsequent publications. One of these circulars [2] is a reply to a pamphlet issued by the National Fertilizer Association advising against the use of raw rock phosphates. This circular shows that the quotations in this pamphlet from the Experiment Station bulletins are very incomplete and the conclusions drawn are unjustified.

In 1910, 1911, and 1912 the Illinois station issued several publications [3] on raw rock phosphates, but only one is quoted here, since the limited duration of the field work or the meager data given in the others hardly justify repetition.

[1] Ill. Agr. Expt. Sta., Circular No. 116; Buls. Nos. 123 and 125 (1908); Circulars Nos. 127 and 130 (1909).

[2] Circular No. 127 (1909).

[3] Lloyd and Brooks, Bul. No. 144 (1910); Hopkins, C. G., Circular No. 141 (1910); Hopkins and Mann, Circular No. 149 (1911); Lloyd, Bul. No. 155 (1912).

In the early part of 1911 the Illinois station issued a circular by Hopkins and Mann.[1] In the first part Mann gives some results obtained with raw ground rock phosphates on his farm, the subdivisions of which were fairly well-drained fields of 85 acres each. Prior to the experiment a 4-year rotation of corn, corn, oats, and clover had been conducted on most of the fields for 30 years. It is not stated if the fields had received applications of lime or other fertilizers. Raw rock phosphate was applied at the rate of 1,000 pounds per acre every four years to the clover just before it was plowed under for the succeeding corn crop. The soil of this farm is largely the brown silt loam of the Early Wisconsin glaciation, commonly called the black prairie land of the corn belt.

The average results of five years' work are given below in Table IX.

TABLE IX.—*Five-year average yields per acre of corn, oats, and clover with and without the use of phosphate.*

Treatment.	Rotation.	Yield per acre.		
		Corn.	Oats.	Clover.
		Bushels.	*Bushels.*	*Tons.*
No fertilizer	2-year, corn and oats	34	32	....
Do	4-year, corn, corn, oats, and clover	54	47	1.5
Phosphate rock, 1,000 pounds every 4 years.	do	70	70	2.5

The results given in Table IX indicate strongly that medium applications of raw rock phosphate were very effective on this particular soil and farm. No field or plots were employed in this experiment, however, on which acid phosphate was applied, so a comparison of the relative merits of the two forms of phosphoric acid is not possible.

In this same circular Hopkins reviews the field work of the Illinois Experiment Station, but gives no detailed results obtained from the use of raw rock phosphate.

The results of seven years' work with raw rock phosphate on the Auburn experiment field, Sangamon County, were published by Hopkins, Mosier, Pettit, and Readhumer[2] in 1911.

A field of 10 acres located on a typical Middle Illinoisan brown silt loam was selected for this experiment. The previous history of the land, however, is not given, nor are any data presented showing the uniformity of the field. Two series of plots were employed, each series containing eight plots, four of which received raw rock phosphate and four no phosphate. A four-year rotation of corn, corn, oats, and clover was followed, corn being represented every year and oats and clover in alternate years.

[1] Ill. Agr. Expt. Sta., Circular No. 149 (1911).
[2] Ill. Agr. Expt. Sta., Soil Rept. No. 4, pp. 7–9 (1912).

While it is stated that raw rock phosphate was applied at the rate of 1 ton per acre at the beginning of the experiment, it is not clear if there were any subsequent applications during the remaining six years of the experiment. No other commercial fertilizers were employed in this test; therefore the data allows no comparison of the relative values of the different phosphates.

All of the plots of this experiment field, with the exception of two, received applications of organic matter either in the form of crop residues or as farm manure.

In Table X the results obtained on eight plots of each series are given.

TABLE X.—*Average yields per acre from two series of plots, Auburn field (1905–1911).*

Treatment.	Corn, 7 crops.	Oats, 3 crops.	Clover, 2 crops.
	Bushels.	*Bushels.*	*Tons.*
Raw rock phosphate	51.9	45.3	2.16
Check	46.2	38.2	1.66
Average gain for raw rock	5.7	7.1	0.50

In commenting on this experiment Hopkins and his coworkers state that "on the whole, the data from favorable seasons strongly indicate a cumulative or increasing effect from the phosphate treatment, as we have reason to expect and as is shown in the latest crops of corn, oats, and clover, the increase amounting to about 25 per cent for oats, 34 per cent for corn, and 48 per cent for clover."

Hopkins[1] also published a paper in 1912 entitled "Shall We Use Complete Commercial Fertilizers in the Corn Belt?" in which he quotes the work of the Indiana and Ohio Experiment Stations with a view to showing that complete mixed fertilizers are inferior and much more expensive than the simple phosphate carriers, and that raw ground rock is the most economic form of phosphoric acid. No data from the Illinois Experiment Station farms are contained in this circular.

In 1913 Hopkins[2] published a paper entitled "Bread from Stones," which consists of a description of an impoverished farm in southern Illinois which the author has made productive by the so-called Illinois system of permanent fertility. The particular tract considered in this paper is a 40-acre field which had been agriculturally abandoned for five years prior to the experiment. During the 10 years

[1] Ill. Agr. Expt. Sta., Circular No. 165 (1912).

[2] Ill. Agr. Expt. Sta., Circular No. 168 (1913).

prior to 1913, in which year the results reported were obtained, the field was cropped with a 6-year rotation, including 1 year each of corn, oats (or cowpeas), and wheat, and 3 years of meadow and pasture with clover and timothy.

The figures obtained seem very favorable to the use of heavy applications (2 tons) of raw rock phosphate, but they are the yields of only one year. A comparison of the yields obtained therefore with and without the addition of raw rock phosphate is probably justified, although the land treated with phosphate rock received twice as much limestone as the plot on which no phosphate was applied. It is possible that the additional amount of lime which this tract received had considerable influence on the large increase in yield.

In the fall of 1913 Hopkins, Mosier, Pettit, and Fisher[1] reported in detail nine-year results of an experiment begun at Galesburg, Ill., in 1904. The soil of this experiment field is the brown silt loam prairie soil of the Upper Illinois glaciation. The field was divided into three series of plots, each series containing 20 plots of one-fifth acre each. A six-year rotation was followed. The previous history of the experiment field is not given.

At the beginning of the experiment limestone was applied to the first 15 plots of each series at the rate of 1,300 pounds per acre, and again to the same plots in either 1912 or 1913 at the rate of 4 tons per acre. In 1904 the first applications of raw ground rock phosphate were made, but the regular plan of this experiment which was to apply 1½ tons per acre of raw ground phosphate rock every six years before plowing for corn was not fully underway on all series of plots until 1906. One hundred pounds of potassium sulphate per acre was applied annually.

It was planned to study the use of phosphate rock, both in grain farming and live-stock farming. In the grain-farming system crop residues are returned to the various plots in proportion to the production of each and in the live-stock system all produce (or its equivalent) is used for feed and bedding and the manure returned to the plots in proportion to their yields during the preceding rotation. In this particular experiment, however, these two systems were not in operation on all series until 1911 and 1912. The average yields of the various crops during the nine years of the experiment are given in Table XI.

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[1] Ill. Agr. Expt. Sta., Soil Rept. No. 7 (1913).

TABLE XI.—*Average of results of nine years' work on three series of plots at Galesburg, Ill.—Six-year rotation employed, consisting of corn, corn, oats, wheat, clover, and timothy.*

Treatment.	Average yield per acre.				
	Corn, 9 years.	Oats, 5 years.	Wheat, 5 years.	Clover, 4 years.	Timothy, 4 years.
	Bushels.	*Bushels.*	*Bushels.*	*Tons.*	*Tons.*
Lime	65.66	48.24	27.98	1.75	1.81
Residues, lime	70.16	47.08	31.16	[1].63	[2]1.43
Manure, lime	77.21	48.34	29.54	2.19	1.90
Cover crop, manure, lime	76.68	50.20	31.06	1.90	1.96
Lime	71.64	49.50	30.66	2.03	1.96
Lime, phosphate rock	78.57	54.64	34.66	2.40	2.18
Residues, lime, phosphate rock	79.68	50.76	35.22	[1].90	[2]1.50
Manure, lime, phosphate rock	81.38	56.80	33.30	2.41	2.11
Cover crop, manure, lime, phosphate rock	82.93	53.56	35.32	2.31	2.27
Lime	73.01	47.28	28.92	1.81	2.05
Lime, phosphate rock, potash	80.89	53.48	34.46	2.53	2.58
Residues, lime, phosphate rock, potash	81.68	52.72	34.74	[1]1.40	[2]1.87
Manure, lime, phosphate rock, potash	81.37	56.36	32.46	2.77	2.20
Cover crop, manure, lime, phosphate rock, potash	83.94	55.50	33.96	2.73	2.26
Lime	74.23	49.60	27.90	1.82	2.10
Residues	72.32	49.42	28.82	[1].82	[2]1.67
Residues, phosphate rock	76.21	51.62	33.78	[1].85	[2]1.80
Residues, phosphate rock, potash	78.38	48.44	36.46	[1]1.51	[2]2.33
Residues, lime, nitrogen, phosphate rock, potash	81.59	56.18	35.95	[1]1.21	[2]2.83
None	70.82	51.98	29.04	1.55	2.08

[1] One crop only. [2] Average of three crops.

While the results given in Table XI are favorable to the use of raw rock phosphate they are not tabulated in a manner which brings out the true effect of this material. Manure was applied only after the experiment had been under way for four years, and the residue (or grain farming) system also was not fully in operation for some years. The average yields of the plots on which "manure" and "residues" were apparently applied therefore include the results of years in which no organic matter was used.

For more detailed figures on this experiment the reader is referred to Soil Report No. 7.

Later this year (1913) the same authors[1] published the results obtained with raw rock phosphate in two complete rotations (nine years) on the Fairfield experiment field, Wayne County, Ill. The soil of this experiment field is the common upland type of southern Illinois, consisting of a gray silt loam on dense clay. The history of the field is not given.

The experiment field was divided into four tracts of 10 acres each, "one half of the field, or 20 acres, is tile drained while the other half has only the ordinary surface drainage. On both the tiled and untiled land grain farming is practiced on one half and live-stock farming on the other half. A part of each of these divisions is treated with 2 tons of limestone and 1 ton of ground phosphate rock per acre every four years." No other commercial fertilizers were used. A four-year rotation was practiced on this field, consisting of corn, soy beans, wheat, and clover, each crop being grown every year on

[1] Ill. Agr. Expt. Sta., Soil Rept. No. 8 (1913).

one of the four tracts. The average results obtained in nine years for each crop on the tiled and untiled land are given in Table XII, which is compiled from four tables given in Soil Report No. 8 of the Illinois station.

TABLE XII.—*Average yields of corn, soy beans, wheat, and clover obtained on four series of plots at Fairfield, Ill., in an experiment conducted for nine years (1905–1913, inclusive).*

Treatment.	Average yield per acre.					
	Corn, 8 years.	Soy beans, 6 years.	Wheat, 7 years.	Clover, 6 years.	Oats, 1 year.	Cowpeas, 4 years.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
Residues, lime, phosphate rock	36.58	8.23	13.79	0.67	35.8	6.08
Crop residues	28.90	6.28	4.17	.45	27.9	5.10
				Tons.		
Farm manure	35.54	6.02	5.21	0.57	32.5	5.68
Manure, lime, phosphate rock	46.91	9.09	18.03	1.61	38.7	7.53
				Bushels.		
Organic manures, lime, phosphate rock	41.86	8.67	15.90	0.82	37.2	6.80
Organic manures	32.21	6.16	4.69	.48	30.2	5.40
Increase due to lime and phosphate rock	9.65	2.51	11.21	.34	7.0	1.75

The authors state that the first four years of this experiment should be regarded as preliminary, partly because of the impossibility of obtaining full benefit from such treatments during the first rotation period, and also because the system of returning manure and crop residues in proportion to the yields produced was not begun until the first rotation was completed. But even taking the average yields of the various crops during both the first and second rotations, it will be seen that the plots treated with large amounts of raw-rock phosphate in connection with lime and organic manures produced considerably larger crops than those receiving no phosphate. The effect of the phosphate, however, was apparently more marked during the second rotation period, as can be seen by referring to the more detailed figures given in Soil Report No. 8 of the Illinois station.

Two experiments with raw-rock phosphate conducted over a period of five years were reported by Hopkins[1] in 1915.

One field at Ewing, Franklin County, consists of a gray silt loam on compact clay (prairie soil), the other at Raleigh, Saline County, is situated on a yellow-gray silt loam of the common upland timber type. The previous history of the fields is not given, however, nor are any data presented showing the uniformity of the fields or the size of the plots into which they were divided. Each field contained 4 series of 10 plots each, and since a four-year rotation of wheat, a legume, oats, and corn was followed, each crop was grown every year. Both live-stock and grain systems of farming were practiced on each farm.

[1] Ill. Agr. Expt. Sta., Circular No 181 (1915).

At the beginning of these experiments limestone was applied on the plots indicated at the rate of 5 tons per acre at Ewing and 6 tons per acre at Raleigh; no further applications were made during the first five years of the experiment. Rock phosphate (finely ground) was applied at the rate of from 500 to 2,000 pounds per acre on the different series and kainit at rates varying from 200 to 800 pounds per acre, with subsequent applications every four years. It is not stated, however, which plots received the maximum and which the minimum amounts of these materials.

The average yield of each crop during the five years of the experiment is given below in Tables XIII and XIV.

TABLE XIII.—*Average results of five years' work on four series of plots at Ewing, Franklin County—Four-year rotation, consisting of wheat, cowpeas (or other legume), oats, and corn.*

Treatment.	Average yield per acre.					
	Wheat, 5 years.	Cowpeas, 3 years.	Clover, 1 year.	Soy beans, 1 year.	Oats, 5 years.	Corn, 5 years.
	Bushels.	*Tons.*	*Ton.*	*Ton.*	*Bushels.*	*Bushels.*
None	5.1	0.63	0.20	0.27	14.3	16.4
Manure	6.7	.52	.24	.23	19.8	23.3
Manure, lime	12.0	.88	.40	.47	23.0	28.9
Manure, lime, phosphate rock	13.7	.98	.81	.53	25.0	30.3
				Bushels.		
None	4.3	[1] 1.46	.19	2.0	14.6	18.0
		Bushels.	*Bushels.*			
Residues	4.1	1.2	.00	2.3	16.4	18.7
Residues, lime	12.4	2.4	.50	4.0	25.4	29.7
Residues, lime, phosphate rock	14.0	3.2	1.08	4.0	24.0	28.4
Residues, lime, phosphate rock, potash	20.7	4.0	.75	4.2	27.2	31.7
			Ton.			
None	5.7	1.3	0.31	2.0	16.9	20.0

[1] One year only.

TABLE XIV.—*Average results of five years' work on four series of plots at Raleigh, Saline County—Four-year rotation, consisting of wheat, cowpeas (or other legume), oats, and corn.*

Treatment.	Average yield per acre.					
	Wheat, 5 years.	Cowpeas, 2 years.	Clover, 2 years.	Soy beans, 1 year.	Oats, 5 years.	Corn, 5 years.
	Bushels.	*Tons.*	*Ton.*	*Ton.*	*Bushels.*	*Bushels.*
None	8.6	2.3	0.33	0.28	11.7	17.2
Manure	7.4	1.8	.33	.30	11.7	24.3
Manure, lime	16.5	4.2	.67	.26	19.9	34.9
Manure, lime, phosphate rock	17.8	3.9	.68	.23	19.0	33.8
				Bushels.		
None	6.9	1.7	[1] .23	.7	10.2	16.6
Residues	8.4	Turned.	Turned.	2.5	12.8	21.1
Residues, lime	18.6	Turned.	Turned.	2.5	19.7	31.3
Residues, lime, phosphate rock	20.7	Turned.	Turned.	2.7	20.0	33.0
Residues, lime, phosphate rock, potash	21.9	Turned.	Turned.	1.8	21.1	34.3
None	7.4	[1] 1.1	[2]	.7	12.7	16.4

[1] One year only. [2] No weight.

The average yields of the various crops as given in Tables XIII and XIV show little or no benefit from the application of phosphate rock, and where the plots so treated do show an average increase for certain crops this increase is practically no greater than the difference between the yields of the check plots. In an experiment of comparatively short duration, however, it is hardly fair to the difficultly soluble material (such as raw rock phosphate) to average the results as has been done in the above tables, since the figures so obtained give no idea of the cumulative effect of the phosphate treatments. As a matter of fact in these experiments the average financial returns from the raw-rock plots during the last two years were over twice as great as in the first three years, seeming to indicate that increasing amounts of organic matter and more thorough distribution of the phosphate were having an important influence in rendering the latter more effective in the soil. The author also points out the facts that the wheat crop in 1912 was a failure throughout the State and that the droughts in 1913 and 1914 were probably more severe than ever known in two consecutive years in the southern part of the State.

In January, 1916, Hopkins, Mosier, Van Alstine, and Garrett[1] reported the results of a number of experiments with raw rock phosphate which included 11 years' work on the Rockford field and 4 years' work on the Mount Morris field. Raw rock phosphate was the only phosphate fertilizer used in these experiments except what was contained in the manure and crop residues returned to the land.

The Rockford experiment field is located about 3 miles from the city of that name in Winnebago County, Ill. The soil of the field is described by the authors as a brown silt loam of the Iowan glaciation. No data are presented showing the relative fertility of the various plots nor is any previous history of the field given in this report. The field, however, was divided into four tracts, which were further subdivided into 20 plots of one-tenth acre each. A four-year rotation consisting of corn, corn, oats, and clover (with soy beans substituted in case of failure of the latter) was begun in 1904, each crop being grown every year on one of the four series of plots. It was planned to practice both grain and live-stock farming systems on this field, but neither system was fully under way until the later years of the experiment. In 1905, however, a legume cover crop was turned under on the plots indicated in three of the series and in 1908 a second growth of clover was turned under on the fourth series for the 1909 crop. Manure was applied on the plots indicated once at the rate of 4 tons per acre. Since 1909 it has been applied according to the live-stock farming system already described. Ground

[1] Ill. Agr. Expt. Sta., Soil Rept. No. 12 (1916).

limestone was applied to plots 1 to 15 at the rate of 1,300 pounds per acre in 1906 and again in 1913 to the same plots at the rate of 4 tons per acre. Raw rock phosphate was applied to the plots indicated at the rate of 1 ton per acre every four years and potash in the form of potassium sulphate was applied at the rate of 400 pounds per acre every four years.[1]

The average results of 11 years with four crops is given in Table XV.

TABLE XV.—*Average results of 11 years' work on four fields at Rockford, Ill.—Four-year rotation, consisting of corn, corn, oats, and clover.*

Treatment.	Average yield per acre.				
	Corn, 11 years.	Oats, 11 years.	Clover, 7 years.	Soy beans, 3 years.	Timothy, 1 year.
	Bushels.	*Bushels.*	*Tons.*	*Bushels.*	*Tons.*
Lime	54.64	57.98	1.83	9.65	1.65
Residues, lime	60.75	61.18	[1] 1.22	10.67	1.66
Manure, lime	68.84	60.76	1.96	14.89	1.65
Cover crop, manure, lime	66.65	59.50	2.04	14.66	1.59
Lime	58.83	54.90	1.91	10.90	1.59
Lime, phosphate rock	61.94	61.59	2.14	11.94	1.44
Residues, lime, phosphate rock	66.44	59.85	[1] 1.96	14.19	1.52
Manure, lime, phosphate rock	71.71	62.22	2.22	18.64	1.47
Cover crop, manure, lime, phosphate rock	69.69	61.86	2.26	19.69	1.45
Lime	57.03	57.18	1.84	16.78	1.47
Lime, phosphate rock, potash	69.73	60.86	2.36	13.02	1.57
Residues, lime, potash, phosphate rock	69.82	61.72	[1] 2.00	13.48	1.53
Manure, lime, potash, phosphate rock	71.75	59.73	2.38	18.44	1.43
Cover crop, manure, lime, potash, phosphate rock	71.80	62.89	2.45	22.30	1.41
Lime	60.19	56.30	1.85	11.13	1.62
Residues	64.40	60.16	[1] 1.94	13.10	1.65
Residues, phosphate rock	67.30	61.70	[1] 1.98	12.63	1.62
Residues, phosphate rock, potash	69.51	63.78	[1] 1.94	12.01	1.45
Residues, lime, nitrogen, potash, phosphate rock	73.25	68.82	[1] 2.08	13.16	2.46
None	54.72	58.83	1.89	10.34	1.40

[1] Average of three years only.

Just as in the case of several other experiments the results as reported here fail to show the cumulative effect of the phosphate treatments; but even taking the average yield of each crop for the entire period the plots on which raw rock phosphate was applied show on the whole considerably better yields than those receiving similar treatments, but no phosphate. By referring to the original tables in Soil Report No. 12 of the Illinois station, which gives the results of each year in detail, it will be seen that the plots receiving organic manures and raw rock phosphate were on the whole considerably more productive during the later than during the earlier years of the experiment, indicating very strongly that the effectiveness of the raw rock phosphate was increasing.

The Mount Morris experiment field[2] is located in Ogle County on a brown silt loam prairie soil. Only the results of four years on one

[1] At the beginning of the experiment, however, potassium sulphate was not applied to each series in like quantity

[2] Ill. Expt. Sta., Soil Rept. No. 12, pp. 18–20 (1916).

series of plots and the results of two years on another series have been thus far reported, so they are not repeated in detail.

Two experiment fields have been established at Urbana[1] to test out the fertilizer value of raw rock phosphate in both grain and live-stock farming systems. One field is on what is known as the "North Farm" and one on the "South Farm." The soil of both fields is the typical brown silt loam prairie land of that region.

The field on the North Farm was in three tracts, which after 20 years or more of pasturing had grown corn in 1895, 1896, and 1897 (when careful records were kept of the yields produced) and had then been cropped with clover and grass on one tract, oats on another, and oats, cowpeas, and corn on the third until 1901. The yields obtained in this preliminary period are not reported in Soil Report No. 12. It is probable, however, that the tracts were not at that time divided into plots, so the relative natural fertility of the 10 plots into which each series was divided for the subsequent experiment is not known.

From 1902 up to the close of 1910 a three-year rotation of corn, oats, and hay was followed, and in 1911 two more series of plots were introduced and a four-year rotation of wheat, corn, oats, and clover (or soy beans) was followed on four series of plots for five years, while on the fifth series alfalfa was grown for five years.

From 1902 to 1908, inclusive, phosphate was applied annually as steamed bone meal at the rate of 200 pounds per acre, but since 1908 one-half of each phosphate plot has been treated with ground raw rock at the rate of 600 pounds per acre per annum—the practice being to add and plow under at one time enough for one complete rotation. Potash was applied at the annual rate of 100 pounds of potassium sulphate per acre.

In the following table only the average results obtained since the introduction of the phosphate-rock treatments (seven years) are given:

[1] Ill. Agr. Expt. Sta., Soil Rept. No. 14, pp. 7–16, October (1916).

TABLE XVI.—*Three and five year average yields per acre of corn, oats, clover, wheat, soy beans, and alfalfa, obtained on North Farm, Urbana, Ill., 1908–1915, inclusive.*

Treatment.	Average yields per acre.								
	1908–1910			1911–1915					
	Corn, 3 years.	Oats, 3 years.	Clover, 3 years.	Wheat, 5 years.	Corn, 5 years.	Oats, 5 years.	Soy beans, 4 years.	Clover, 1 year.	Alfalfa, 5 years.
	Bush.	*Bush.*	*Tons.*	*Bush.*	*Bush.*	*Bush.*	*Tons.*	*Tons.*	*Tons.*
None	49.4	40.8	2.30	22.2	53.9	46.3	1.60	2.50	2.27
Crop residues	51.5	43.4	[1] (1.93)	23.5	56.4	47.8	[1] (21.3)	[1] (0.74)	1.85
Manure	69.3	46.2	2.53	24.8	63.6	54.6	1.68	2.20	1.68
Residues, lime	58.1	45.7	[1] (2.02)	25.0	59.2	49.7	[1] (20.7)	[1] (1.03)	1.72
Manure, lime	74.9	47.5	2.94	28.1	63.4	57.3	1.72	2.81	2.25
Residues, lime, phosphate rock, 600 pounds	83.8	54.5	[1] (2.64)	39.1	66.0	64.3	[1] (22.6)	[1] (2.48)	3.28
Manure, lime, phosphate rock, 600 pounds	86.6	55.4	4.17	38.3	67.6	64.9	1.92	4.04	3.25
Residues, lime, phosphate rock, potash	86.7	53.5	[1] (1.99)	38.2	63.7	64.5	[1] (24.2)	[1] (1.41)	3.22
Manure, lime, phosphate rock, potash	90.9	53.6	3.90	37.4	64.6	69.3	2.09	3.91	3.31
Manure, lime, phosphate rock	81.3	54.3	3.79	42.9	61.0	72.5	2.19	4.24	3.45

[1] Bushels of seed.

The plots receiving phosphate treatments in every instance gave substantially greater average yields than those on which no phosphate was applied. These increases, however, can not be entirely attributed to raw rock phosphate, since the previous applications of steamed bone meal no doubt influenced considerably the crop yields. The results of one or more additional rotations should be obtained before it is wise to draw conclusions from this experiment.

On the South Farm, at Urbana, a four-year rotation is practiced on two series of plots. Raw rock phosphate has been applied at the rate of 500 pounds per acre per annum and ground limestone at the rate of 8 tons per acre once in 1910 and 1911. Beginning in 1912 the subsequent applications of limestone were at the rate of 2 tons per acre every four years.

The average results of 12 years' work on two series of plots on the South Farm are given below in Table XVII.

TABLE XVII.—*Average annual yields of crops grown in a four-year rotation on two series of plots on South Farm, Urbana, Ill., 1903–1915, inclusive.*

Treatment.	Average yield per acre.				
	Corn, 7 years.	Oats, 7 years.	Wheat, 7 years.	Clover, 3 years.	Soy beans, 2 years.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
Residues, phosphate rock	60.2	40.6	40.4	0.71	15.2
Residues, phosphate rock	59.1	39.5	38.7	1.15	14.9
Residues	50.6	35.9	28.5	1.30	13.0
				Tons.	*Tons.*
Manure	54.6	36.6	28.7	2.72	1.0
Manure, phosphate rock	59.1	38.8	41.2	3.94	1.3
Manure, phosphate rock	60.9	38.8	42.0	3.99	1.4

TABLE XVII.—*Average annual yields of crops grown in a four-year rotation on two series of plots on South Farm, Urbana, Ill., 1903–1915, inclusive*—Contd.

	3 years.	2 years.	3 years.	Not grown.	2 years.
					Bushels.
Residues, lime, phosphate rock [1]	62.4	53.6	47.9	....	13.7
Residues, lime, phosphate rock [1]	61.5	52.8	46.5	....	12.3
Residues [1]	53.8	42.7	28.6	....	10.7
					Tons.
Manure [1]	58.4	47.6	29.5	....	0.84
Manure, lime, phosphate rock [1]	63.0	48.5	49.4	....	1.17
Manure, lime, phosphate rock [1]	63.2	50.2	48.7	....	1.34

[1] Plots on which lime was applied were not introduced into the experiment until 1910.

The results of this experiment point very strongly to the conclusion that raw rock used in liberal amounts in connection with organic manures is effective in increasing crop yields. But like many other experiments no data are reported which allow one to determine the relative efficiency of raw rock and acid phosphate.

In April 1916 Hopkins [1] reported the results of three long-time experiments at Cutler, Odin, and Mascoutah, in southern Illinois. These are the only experiments reported by Hopkins of Illinois work comparing the fertilizer value of steamed bone, acid phosphate, ground raw rock phosphate, and basic slag. Crop residues were returned to the land and potash and lime applied. At Odin and Mascoutah only half of each plot was limed. Fertilizers were applied once during each rotation in sufficient quantity to supply annually 200 pounds bone, 333 pounds acid phosphate, 666 pounds raw rock, and 260 pounds slag (equal money values at that time). The results of the experiments are given below in Tables XVIII and XIX.

TABLE XVIII.—*Average yields of corn, oats, wheat, and hay in two long-time experiments.*

Treatment.	Odin field (1904–1915).			Mascoutah field (1904–1913).[2]		
	Corn, 3 crops.	Oats, 3 crops.	Hay, 6 crops.	Corn, 4 crops.	Oats, 2 crops.	Wheat, 2 crops.
	Bushels.	*Bushels.*	*Tons.*	*Bushels.*	*Bushels.*	*Bushels.*
Residues, lime, bone, potash	33.9	47.8	1.30	45.4	38.6	26.3
Residues, bone, potash	31.4	50.9	.94	48.6	42.6	25.9
Residues, lime, potash	26.7	43.9	1.07	38.9	37.2	23.6
Residues, potash	27.6	43.9	.64	39.7	27.3	22.6
Residues, lime, acid phosphate, potash	30.2	43.5	1.19	44.0	37.0	25.4
Residues, acid phosphate, potash	29.9	52.8	.77	40.2	42.2	25.7
Residues, lime, rock phosphate, potash	32.3	48.4	1.28	47.2	38.9	26.7
Residues, rock phosphate, potash	27.0	52.2	.72	45.6	37.4	26.2
Residues, lime, potash	27.3	48.1	1.12	38.4	40.5	25.1
Residues, potash	21.7	41.1	.61	38.6	31.0	20.7
Residues, lime, basic slag, potash	32.7	56.8	1.27	45.6	43.0	26.5
Residues, basic slag, potash	27.3	50.3	.78	47.8	33.8	25.8

[1] Ill. Agr. Expt. Sta. Circular No. 186, April, 1916.

[2] Crops of legumes turned under in 1908 and 1911.

TABLE XIX.—*Average yields of corn, wheat, legumes, and oats, Cutler field.*

Treatment.	Average yield per acre (1904-1915).			
	Corn, 4 crops.	Wheat, 3 crops.	Legumes, 1 crop.	Oats, 2 crops.
	Bushels.	*Bushels.*	*Tons.*	*Bushels.*
Residues, lime, bone, potash	34.9	25.1	2.74	27.1
Residues, lime, potash	38.4	16.9	2.11	31.6
Lime, potash	36.9	16.3	1.80	25.5
Residues, lime, acid phosphate, potash	36.0	28.7	2.52	28.8
Lime, acid phosphate, potash	37.1	26.6	2.40	31.8
Residues, lime, phosphate rock, potash	42.2	25.8	2.51	24.6
Lime, phosphate rock, potash	37.3	18.5	2.06	29.3

In almost every instance plots treated with ground raw rock phosphate gave noticeable increases in yield over the check plots, and at Odin and Mascoutah showed to better advantage than the acid phosphate plots. At Cutler the acid phosphate plots appeared to greater advantage. However, none of the phosphate treatments gave very large increases, and, as Hopkins says, "These investigations have shown that phosphorus is not the factor which first limits the crop yields on these southern Illinois soils, both limestone and organic matter being of greater initial importance." Owing to the adverse climatic conditions during the latter part of the experiment it is impossible to tell whether or not any cumulative effect can be attributed to the use of raw rock.

The data presented in the 12 field experiments with raw rock phosphate conducted by the Illinois station and considered here in detail point pretty strongly to the conclusion that this phosphate carrier increases crop yields very materially when applied liberally. Since raw rock was compared with other phosphates in only 3 of the 12 experiments, and on fields where phosphoric acid apparently was not the limiting factor, the work hardly appears to justify a comparison of the relative merits of the different phosphate carriers.

INDIANA.

The first mention of the use of raw rock phosphate as a fertilizer made by the Indiana Experiment Station was in 1896,[1] when phosphatic marl containing from 10 to 12 per cent of phosphoric acid was tried on two series of wheat plots of one-twentieth acre each. The short duration of this experiment (one year), however, and the little data presented make the results relatively unimportant.

Two experiments with raw rock phosphate were described by Goss[2] in 1907 and several others by Abbott and Conner[3] in 1912,

[1] Ind. Agr. Expt. Sta., Bul. No. 61, p. 64 (1896).
[2] Ind. Agr. Expt. Sta., Circular No. 10, pp. 9–11 (1907).
[3] Ind. Agr. Expt. Sta., Bul. No. 155 (1912).

but none of these were conducted for a period of more than four years, so the results are not considered in detail.

All the other experiments with raw rock phosphate conducted by the Indiana station are described and discussed by Wiancko and Conner[1] in a recent bulletin entitled "Acid Phosphate versus Raw Rock Phosphate as Fertilizer."

Two of these experiments, one at Littles, in Pike County, and the other at Scottsburg, Scott County, were begun at the same time (1905), and are similar in every respect. There are three series of plots of one-twentieth acre each, and a three-year rotation of corn, wheat, and clover has been practiced, so that each crop could be grown on one series every year. "When the clover failed cowpeas or soy beans were substituted. The land was plowed once in three years for corn, except when clover failed, when it was also plowed for soy beans or cowpeas. The wheat was drilled on disked corn stubble and the clover seeded on the wheat in the spring." The various fertilizers were all applied to the wheat in the first round of the rotation, the treatment being as follows: Manure at the rate of 10 tons per acre, raw rock at the rate of 1 ton per acre, and acid phosphate drilled with the wheat at the rate of 150 pounds per acre. After the first rotation manure was again applied at the same rate on every corn crop and acid phosphate on every wheat crop. A second ton of raw rock phosphate was applied for corn and cowpeas in 1911 and 1912. Both fields were limed in 1911 at the rate of 2 tons of finely ground limestone per acre. While there were three check plots in each of the three series, the various fertilizer materials were represented by only one plot in each series.

The field at Littles is nearly level with a slight slope running lengthwise of the plots. The soil is described as a yellowish brown silt loam of medium fertility. The phosphoric acid content as determined by analysis is 0.13 per cent.

The Scottsburg field is almost level on one series, but rises gradually through the two other series of plots. The soil is Volusia silt loam and is considered of low fertility. The total phosphoric acid content as determined by analysis is less than 0.1 per cent. The average yields of the three crops on both fields during the 10 years of the experiment are given in Tables XX and XXI.

[1] Ind. Agr. Expt. Sta., Bull. No. 187, vol. 18 pp. 1055–1082 (1916).

TABLE XX.—*Average yields of corn, wheat, and legumes obtained in a 10-year experiment on three series of plots at Littles, Pike County, Ind. (1906–1915).*

Treatment.	Average yield per acre.				
	Corn, 8 crops.		Wheat, 10 crops.		Legume, 3 crops.
	Ear corn.	Stover.	Grain.	Straw.	Hay.
	Bushels.	*Pounds.*	*Bushels.*	*Pounds.*	*Pounds.*
Nothing	41.8	3,298	13.3	1,149	3,987
Acid phosphate, 150 pounds [1]	41.9	3,288	15.0	1,407	4,353
Rock phosphate, 1 ton	39.2	3,030	14.7	1,293	3,913
Nothing	37.7	2,990	13.7	1,122	3,767
Rock phosphate, 1 ton; [2] manure, 10 tons [1]	46.9	3,435	18.6	1,769	4,930
Manure, 10 tons [1]	47.4	3,698	18.4	1,769	4,043
Nothing	41.0	3,427	14.9	1,491	3,793

[1] Per rotation.
[2] Rock phosphate applied at the above rate twice during 10 years.

TABLE XXI.—*Average yields of corn, wheat, and legumes obtained in a 10-year experiment at Scottsburg, Scott County, Ind. (1906–1915).*

Treatment.	Average yield.				
	Corn, 8 crops.		Wheat, 10 crops.		Legume, 3 crops.
	Ear corn.	Stover.	Grain.	Straw.	Hay.
	Bushels.	*Pounds.*	*Bushels.*	*Pounds.*	*Pounds.*
Nothing	25.1	2,366	9.2	862	749
Acid phosphate, 150 pounds [1]	34.3	2,817	15.6	1,392	1,412
Rock phosphate, 1 ton [2]	40.4	2,988	13.9	1,311	1,396
Nothing	30.5	2,578	10.2	992	1,291
Rock phosphate, 1 ton; [2] manure, 10 tons [1]	51.2	4,114	20.8	2,138	3,151
Manure, 10 tons [1]	50.5	4,025	20.0	2,073	3,065
Nothing	30.5	2,583	10.4	1,061	1,523

[1] Per rotation.
[2] Rock phosphate applied at the above rate twice during 10 years.

The average results of 10 years' work on the Littles field are not very satisfactory, since the difference between the average yields of certain check plots is greater than the difference between the checks and the plots treated with phosphates. Moreover the yields of all crops (except the legumes) on some of the checks were practically as good and in some cases better than the yields on the plots treated with phosphates alone, indicating that the soil was not very responsive to phosphate treatments. Only in the case of the legume hay did acid phosphate seem appreciably more beneficial than raw rock; in fact, it was on this crop only that the former appeared at all effective. More significant increases in the yields of legumes were obtained, however, on plots receiving manure reenforced with phosphate rock.

On the Scottsburg field the effect of phosphate treatments seemed much more marked, the average yields of the fertilized plots being

well above those of the checks. In this experiment the raw-rock plots gave average yields comparing favorably with those treated with acid phosphate.

The writers feel, however, that the method of application used in these experiments hardly admits of a fair comparison of the relative merits of ground raw rock and acid phosphate. Nearly three times the amount of money was invested in raw rock during the 10 years as in acid phosphate. This means that in order to show a profit comparing favorably with that obtained on the acid-phosphate plots the increases in yield from raw-rock plots must be three times as great. On a field showing little or no response to phosphate treatments (such as the Littles field) it appears to the writers unwise to attempt to compare the two forms of phosphoric acid when the rock-phosphate plot was so heavily handicapped. Considering now the Scottsburg experiment, the only instance where there is any significant difference shown between the yields of the plots receiving the two forms of phosphoric acid is in the corn crop, where the average yield of the raw-rock plot was considerably greater than that of the plot treated with acid phosphate.

Four other experiments with raw rock phosphate undertaken by the Indiana station are described in this same paper, but none of them cover a period of over four years, so they do not warrant detailed discussion.

The work of the Indiana station on the whole, while not conclusive, gives evidence of increased crop yields resulting from applications of raw rock phosphate. Under the conditions of the experiments any attempt to form conclusions concerning the relative merits of raw rock and acid phosphate seems unwarranted.

KENTUCKY.

The first data of the Kentucky station pertaining to the use of raw rock phosphate as a fertilizer were published in 1899.[1] They consisted of the results obtained from a one-year experiment with various phosphate carriers on wheat.

The same cooperator continued the experiment the following year,[2] but employed a different field and discontinued the application of ground rock phosphate. The results of this experiment are not repeated here.

In 1912 the Kentucky station in cooperation with the State Geological Survey published a paper[3] containing the results of three series of pot experiments with a yellow silt loam of rather low phosphate content. In series 1 and 3, pots of 4 gallons capacity were

[1] Ky. Agr. Expt. Sta. Bull. No. 83, pp. 35–38 (1899).
[2] Ky. Agr. Expt. Sta., Bul. No. 89 (1900).
[3] Ky. Agr. Expt. Sta., Bul. No. 162 (1912).

employed containing 30 pounds of soil each, and in series 2, pots one-half this size (2 gallons) containing 15 pounds of soil were used.

Series 1 was planted to tobacco the first year, followed by oats the second year. Series 2 was planted to clover the first year, followed the second year by tobacco. Series 3 was planted to wheat the first year and to clover the second year.

In each instance after the first crop was harvested the soil was dried, emptied out of the pots, mixed thoroughly with the fertilizers for the following crop, and then returned to the pots. The results of these experiments are given in part in Tables XXII, XXIII, and XXIV.

TABLE XXII.—*Yields of tobacco and oats obtained in pot tests with various fertilizers.*

SERIES I.—TOBACCO (4-GALLON POTS).

Fertilizer.	Application per pot.	Yield of stalks and leaves per pot.	Increase per pot.	Relative increase
	Grams.	*Grams.*	*Grams.*	*Per cent.*
None		[1] 13.8		
Limestone	15.0	12.0	−1.75	−12.7
Dissolved bone (24 per cent P_2O_5)	3.8	10.3	−3.75	−27.2
Rock phosphate	20.0	13.2	−0.55	− 4.5
Manure	35.0	9.7	−4.05	−29.4
Do	35.0	10.3	−3.45	−25.1
Rock phosphate	20.0			

SERIES I.—OATS (AFTER TOBACCO).

Fertilizer.	Application per pot.	Whole crop.		Grain.		
		Yields per pot.	Increase per pot.	Yield per pot.	Increase per pot.	Relative increase.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Per cent.*
None		[1] 47.5		[1] 10.1		
Limestone	15.0	61.0	13.5	13.5	3.4	33.6
Dissolved bone (24 per cent P_2O_5)	3.7	83.0	35.5	15.0	4.9	48.5
Rock phosphate	20.0	68.5	21.0	13.4	3.3	32.7
Manure	35.0	93.5	46.0	16.5	6.4	63.4
Do	35.0	84.0	36.5	15.4	5.3	52.4
Rock phosphate	20.0					

[1] Average of 2 pots.

TABLE XXIII.—*Yields of clover and tobacco obtained in pot tests with various fertilizers.*

SERIES II.—CLOVER (2-GALLON POTS).

Fertilizer	Application per pot.	Weight of three cuttings per pot.	Increase per pot.	Relative increase.
	Grams.	*Grams.*	*Grams.*	*Per cent.*
None		16.0		
Limestone	7.5	20.4	4.4	27.5
Dissolved bone	1.9	32.1	16.1	100.6
Rock phosphate	10.0	30.8	14.8	92.5
Manure	17.5	25.7	9.7	60.6
Rock phosphate	10.0	27.6	11.6	72.5
Manure	17.5			

TABLE XXIII.—*Yields of clover and tobacco obtained in pot tests with various fertilizers*—Continued.

SERIES II.—TOBACCO (AFTER CLOVER).

Fertilizer.	Application per pot.	Stalks and leaves per pot.	Increase per pot.	Relative increase.
	Grams.	*Grams.*	*Grams.*	*Per cent.*
None		[1] 3.75		
Limestone	7.5	5.00	1.25	33.3
Dissolved bone	1.9	4.60	.85	22.7
Rock phosphate	10.0	7.40	3.65	97.3
Manure	17.5	9.50	5.75	153.3
Do.	17.5	7.60	3.85	102.4
Rock phosphate	10.0			

[1] Average of two pots.

TABLE XXIV.—*Yields of wheat and clover obtained in pot tests with various fertilizers.*

SERIES III.—WHEAT (4-GALLON POTS).

Fertilizer.	Application per pot.	Whole crop.		Grain.		
		Yield per pot.	Increase per pot.	Yield per pot.	Increase per pot.	Relative increase.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Per cent.*
None		[1] 34.9				
Dissolved bone	3.8	44.6	9.7	14.6	2.7	22.7
Rock phosphate	20.0	45.6	10.7	15.7	3.8	31.9
Manure	35.0	44.5	9.5	16.2	4.3	36.1
Do.	35.0	36.3	1.4	14.9	3.0	25.2
Rock phosphate	20.0					

SERIES III.—CLOVER (AFTER WHEAT).

Fertilizer.	Application per pot.	Weight of first cutting per pot.	Weight of second cutting per pot.	Total per pot.	Increase per pot.	Relative increase.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Per cent.*
None		[1] 13.8				
Dissolved bone	3.8	45.3	24.6	70.4	41.05	139.9
Rock phosphate	20.0	32.2	21.0	53.2	23.85	81.3
Manure	35.0	46.5	25.0	71.5	42.15	143.6
Do.	35.0	36.5	24.5	61.0	31.65	107.8
Rock phosphate	20.0					

[1] Average of two pots.

It will be noticed that the pots receiving applications of phosphates, whether water soluble or relatively insoluble, gave considerable increases in yield over the untreated pots, except in series I, where tobacco was grown the first year.

The soluble phosphate on the whole gave somewhat better yields than the ground rock, although the latter material was applied liberally. In the second year of series II, however, when tobacco was grown, the ground-rock pot gave a much greater yield than the pot treated with acid phosphate. Contrary to what one would expect, the pots treated with a mixture of rock phosphate and manure gave

lower yields in nearly every case than those treated with manure alone. In three out of six cases ground rock alone exceeded a mixture of ground rock and manure.

In this publication the authors state that these experiments were to be continued, but no further results of the tests have yet been published.

In 1914 the Kentucky station, in a bulletin on "Alfalfa and Sweet Clover,"[1] gave the results obtained in a single season with these crops when treated with raw rock and acid phosphate, but since the work was not continued beyond one year and the data given are very limited the figures are not repeated.

In 1915 and 1916 Roberts[2] published the results of an experiment conducted at Burnside, Pulaski County, which had been running since 1908. The field used lies on a hillside of moderate slope. The soil consists of a badly worn limestone clay, very low in organic matter, which had produced poor crops for a long time; practically no manure had been returned to it for many years. In 1908, less than 3½ bushels of wheat per acre were produced on this field, although it had received 200 pounds per acre of an 8–2–2 fertilizer.

In the summer of 1908, after the wheat was harvested, the field was laid out in six plots of one-fourth acre each, and the following fertilizers were applied on the unbroken ground and plowed under: Phosphate rock, 2,000 pounds per acre; acid phosphate, 800 pounds per acre; muriate of potash, 400 pounds per acre. Cowpeas were then sown and later turned under. The plots were then planted to rye and vetch, and while the latter crop failed the rye made a good growth. In the case of both cowpeas and rye the acid phosphate plots gave greater yields.

No more fertilizer was applied until 1911, then a light dressing of manure was added to each plot, equivalent to what the corn and oats crops of each plot would make. In 1912 another such application of manure was added to the plots in addition to the same applications of fertilizer materials as in 1908. In the spring of 1914 a uniform dressing of nitrate of soda was applied to all plots because wheat was so backward. Manure was again added at the same rate as before in 1915, and potash and phosphates at one-fourth the rate previously employed.

The results of seven years' work are given in detail in Table XXV.

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[1] Ky. Agr. Expt. Sta., Bul. 178 (1914).
[2] Ky. Agr. Expt. Sta., Bul. No. 191 (1915); Bul. No. 199 (1916).

TABLE XXV.—*Results of seven years' work on Burnside experiment field (1909–1915).*

Fertilizer.	Application per acre.[1]	Yield per acre.						
		Corn, 1909.	Oats, 1910.	Clover, 1911.	Corn, 1912.	Soybean hay, 1913.	Wheat, 1914.	Corn, 1915.
	Pounds.	*Bushels.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Bushels.*
Rock phosphate Potash	2,000 400	3.8	9.3	2,436	32.9	1,688	11.9	34.8
Nothing		9.0	9.0	668	9.5	628	2.5	4.9
Acid phosphate Potash	800 400	14.3	11.9	2,168	45.7	2,272	19.2	46.6
Acid phosphate	800	17.7	13.6	2,328	43.5	2,112	18.1	50.9
Nothing[2]		20.4	14.0	1,292	30.3	1,176	5.1	18.5
Potash	400	11.9	10.5	764	17.6	560	1.7	5.3

[1] The fertilizers were applied at rate per acre stated in summer of 1908, again at the same rate in 1912, and at one-fourth the above rate in 1915.
[2] The station states that this plot should not be considered a check plot.

While the plot treated with raw rock phosphate and potash gave yields below and no better than the check plots in 1909 and 1910, respectively, from then on it forged ahead rapidly, indicating that the crops were benefited by the phosphate treatments after the latter became more thoroughly distributed in the soil through cultivation. The yields of the acid phosphate plots, however, greatly exceeded (in all but one instance) those of the raw-rock plot, even though the less soluble material added over four times as much phosphoric acid to the soil. While no data are given showing their relative natural fertility, it is said that the raw-rock plot was handicapped by being naturally less fertile than the other plots in the experiment field.

The results of six other experiments comparing acid phosphate with raw rock phosphate, conducted for periods of from three to four years in various parts of the State, are given by Roberts in this same bulletin. Their limited duration, however, coupled with the fact that the weather conditions were very bad during two of the years, render detailed considerations of the results unwarranted in this paper.

The data presented by the Kentucky station are insufficient to be conclusive, although the results of the field experiment cited did indicate that raw rock, while inferior to acid phosphate, increased crop yields after the lapse of a year or more.

LOUISIANA.

Of the 13 experiments with ground rock phosphate or "floats" carried on by the Louisiana Experiment Station, 10[1] were conducted through periods of from one to four years. These are not repeated in detail.

[1] La. Agr. Expt. Sta., Buls. Nos. 3, 4, 6 (1886); 7, 8, 11 (1887); 14 (1888); 20 (1889); 28 (1890) (old series). Buls. Nos. 8 (1891); 14, 16 (1892); 26, 29 (1894) (new series).

In 1889, however, the North Louisiana Experiment Station, at Calhoun, La.,[1] began a five-year experiment to test the effect of various phosphatic fertilizers (alone and in combination with other materials) on cotton. The results were published year by year, but in no bulletin is there a table giving the complete results for all five years. They have been consolidated by the authors in Table XXVI.

Neither the size of the plots nor the character of the soil used in this experiment are mentioned, but the soil at the station is said to be on the whole sandy. The field was plowed during the winter of each year, the fertilizer drilled in in the spring, and the seed planted shortly afterwards. The crop was cultivated and hoed several times during each growing season.

The climatic conditions during the third and fifth years are not described, but during 1889, and in July and August of 1890, droughts somewhat handicapped the crops. In 1892 late planting and excessive rains seriously affected the yields for that year.

TABLE XXVI.—*Results obtained in the growing of cotton on plot No. 2 (Calhoun, La.) (1889–1893).*

Fertilizer.	Application per acre.	Yield per acre of seed cotton.				
		1889	1890	1891	1892	1893
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Gypsum	80	1,520	1,810	1,860	730	1,250
Dissolved bone black	160	1,630	1,770	1,870	820	1,240
Basal mixture [1]	600	1,970	1,800	1,780	710	1,540
Basal mixture [1]	600					
Dissolved bone black	160 320	[2] 1,990	[2] 2,133	[2] 2,215	[2] 920	[2] 1,645
Gypsum	80	1,390	1,620	1,710	760	1,320
Acid phosphate	160	1,350	1,680	1,620	780	1,160
Basal mixture [1]	600	1,720	1,870	1,700	920	1,450
No manure	....	1,010	1,210	1,380	520	960
Basal mixture [1]	600					
Acid phosphate	160 320	[2] 1,950	[2] 1,760	[2] 1,735	[2] 680	[2] 1,285
Bone meal	160	770	1,180	1,330	590	890
Basal mixture [1]	600	1,170	1,370	1,480	660	1,170
Basal mixture [1]	600					
Bone meal	160 320	[2] 1,305	[2] 1,335	[2] 1,545	[2] 700	[2] 1,130
Floats	160	480	690	1,030	460	610
Basal mixture [1]	600	920	1,100	1,190	560	1,100
Basal mixture [1]	600					
Floats	160 320	[2] 835	[2] 1,015	[2] 1,255	[2] 680	[2] 880
No manure	....	330	630	730	380	470

[1] Basal mixture = 480 pounds cotton-seed meal and 200 pounds kainit.
[2] Average of two plots.

It is apparent that the plots of this experimental field were far from uniform. Moreover, small applications of raw rock phosphate (160 pounds per acre) used on continual cotton without incorporating more organic matter in the soil than was supplied in the basal mixture employed in this experiment could hardly be expected to produce marked effects on the crop yield.

[1] La. Agr. Expt. Sta., Bul. No. 27 (1889) (old series). Buls. Nos. 8 (1891); 16 (1892); 26, 29 (1894) (new series).

In 1889 the North Louisiana Experiment Station began a number of experiments with corn.[1] One of these had for its object the testing of the effect of various phosphatic fertilizers alone and in combination on the crop yields. This experiment was carried on for five years, but the raw phosphates were not introduced until the second year. The results obtained each year were published in separate bulletins,[2] but for the sake of brevity and clearness they are here all incorporated in one table. As in the case of the cotton experiments carried on at this same station, the size of the plots employed is not mentioned, and the only description given of the soil is that it was poor.

The land was plowed during the winter and fertilized in the spring. The corn was planted in rows 5 feet wide and 3 feet apart in the drill. The complete results are given below in Table XXVII.

TABLE XXVII.—*Results obtained at Calhoun, La., in the growing of corn (1889–1893).*

Fertilizer.	Application per acre.	Yield per acre of corn.				
		1889	1890	1891	1892	1893
	Pounds.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
Gypsum	56	26.69	21.00	15.00	13.60	16.00
Dissolved bone black	112	28.00	23.00	12.75	25.20	19.60
Basal mixture	336	25.00	28.00	14.25	32.80	22.00
Do. Dissolved bone black	420 112	22.00	23.14	12.75	25.60	21.80
Gypsum	56	14.49	14.42	6.00	10.80	8.80
Acid phosphate	112	13.00	12.17	5.25	17.20	8.80
Basal mixture	420	20.00	18.25	10.50	18.80	16.80
No manure		12.00	11.00	4.50	8.40	7.60
Basal mixture Acid phosphate	420 112	22.19	18.13	13.88	23.20	24.00
Bone meal	112	14.10	13.00	10.50	11.20	17.60
Basal mixture	420	17.00	20.32	13.50	29.40	21.60
Do. Bone meal	420 112	17.50	20.78	17.25	31.20	24.80
South Carolina floats	112		9.00	6.75	13.60	15.60
Basal mixture	420		22.00	14.25	28.40	20.40
Do. South Carolina floats	420 112		21.75	15.75	29.80	22.40
No manure			9.10	6.75	14.00	10.50

The wider differences between the yields of the various plots receiving "basal mixture" show that this field was not of uniform fertility.

A careful study of Table XXVII will also show that the soil seemed to respond much more readily to the nitrogenous than to the phosphatic fertilizers, but the applications of the latter were rather light, particularly for the relatively insoluble phosphates. With the exception of those treated with bone or dissolved bone black, the plots on which phosphates were applied alone gave on the whole little or no increase in yield over the unfertilized plots. While floats alone gave no increase in yield for the first three years of the experiment, the crop produced the fourth year on this plot exceeded the no-fertilizer plots by a considerable margin, indicating that

[1] La. Agr. Expt. Sta. Bul. No. 27 (1890).
[2] La. Agr. Expt. Sta., Buls. Nos. 8, 16, 21 29 (new series).

there was a cumulative effect. When the phosphates were used in connection with the "basal mixture," however, their effect seemed more marked. A comparison of the phosphate-basal-mixture plots shows that the bone meal and floats gave on the whole higher yields than either dissolved bone black or acid phosphate, but these differences are negligible when compared with the differences in yield between the various "basal-mixture" plots.

A fertilizer experiment with sugar cane begun at Audubon in 1890, was continued for 10 years, and in 1900 the averages of the results obtained during that period were published.[1] There were, however, during this period only eight crops of cane harvested.

The land selected for this experiment was part of Audubon Park and had not been under cultivation for years. It had grown the native deep-rooted grasses which had sometimes been cropped for hay, but more frequently allowed to decompose on the fields. The soil, therefore, was rich in organic matter and might be considered at the outset almost new. No description is given of the soil type. The land was tile-drained. The fertilizers were applied only in those years in which cane was grown and raw rock phosphate was not introduced into the experiment until 1891. The acidulated phosphates were applied at the rate of 250 pounds per acre when used alone, but when used in conjunction with potash and nitrogen carriers they were applied at two rates, namely, 250 pounds and 500 pounds per acre. The less soluble phosphates, bone, basic slag, and South Carolina "floats" were applied at the rate of 500 pounds per acre throughout.

The results are given in Table XXVIII.

TABLE XXVIII.—*Eight-year average results obtained at Audubon Park, La., in the growing of sugar cane (1890–1900).*

Fertilizer and annual application per acre.[2]	Average yield per acre.	
	Cane.	Sucrose in juice.
	Tons.	*Per cent.*
Dissolved bone black, 250 pounds	29.88	11.77
Dissolved bone black, 250 and 500 pounds; basal mixture,[3] 330 pounds	[4] 29.52	[4] 10.64
Basal mixture,[3] 330 pounds	28.19	10.84
Acid phosphate, 250 pounds	26.12	11.55
Acid phosphate, 250 and 500 pounds; basal mixture,[3] 330 pounds	[4] 29.55	[4] 11.04
No fertilizer	25.10	11.59
Bone black, 500 pounds	27.26	11.37
Bone black, 500 pounds; basal mixture,[3] 330 pounds	27.59	11.35
Slag meal, 500 pounds	27.68	11.62
Slag meal, 500 pounds; basal mixture,[3] 330 pounds	30.44	11.82
Basal mixture,[3] 330 pounds	28.45	11.70
South Carolina floats, 500 pounds	26.76	12.04
South Carolina floats, 500 pounds; basal mixture,[3] 330 pounds	29.19	11.67
No fertilizer	25.38	12.29
Bone meal, 500 pounds	26.73	12.26
Bone meal, 500 pounds; sulphate of potash, 100 pounds	26.03	12.34
Bone meal, 500 pounds; basal mixture,[3] 330 pounds	27.44	11.96

[1] La. Agr. Expt. Sta., Bul. No. 59 (new series) (1900).
[2] Fertilizer applications made only in years cane was grown (8 years).
[3] Basal mixture = 230 pounds ammonium sulphate and 100 pounds potassium sulphate.
[4] Average of two plots.

The results given in Table XXVIII indicate strongly that medium applications of phosphate, either soluble or relatively insoluble, produced appreciable increases in the yield of sugar cane. The yields on the whole were slightly in favor of the acidulated phosphates, but the average yield of the plot treated with a combination of basic slag and "basal mixture" exceeded those of all the other plots. The plot treated with dissolved bone black alone gave the next highest yield, followed by the plots receiving mixtures of the acidulated phosphates (dissolved bone black and acid phosphate) and "basal mixture." The yield of the floats-basal mixture plot, however, was so close to that of the latter two that the difference is well within experimental error. When applied alone, South Carolina "floats" and bone meal apparently gave about equal results, the yields being greater than that of the acid-phosphate (alone) plot.

In two out of the three experiments of the Louisiana station here cited, the applications of raw rock were so light and the evidence points so strongly to the lack of uniformity in the experiment fields that the results have little value. In the third experiment, however, where the phosphates were applied more liberally the increased yields of sugar cane obtained from the insoluble-phosphate treatments compared favorably with those from the soluble-phosphate plots.

MAINE.

Owing to the limited data presented and their short duration (from one to two years), six[1] of the nine experiments with raw rock phosphate conducted by the Maine Experiment Station are not considered in this paper.

In 1895[2] the Maine station published the results of two field experiments with various forms of phosphoric acid. One was conducted for nine years and the other for seven years.

The first experiment was conducted on a 2-acre field which was divided into 36 plots containing one-twentieth acre each. The soil of this field was a clay loam and said to be quite uniform throughout. Before the sod was broken for the experiment in 1885 the field had grown three heavy crops of grass, previously to which it had received a liberal application of stable manure and unleached wood ashes. In 1885, without any further addition of fertilizer, the field produced a crop of barley.

Fertilizers were applied only five times during the nine years of this experiment, no applications being made in 1888, 1890, 1891, and

[1] Me. Agr. Expt. Sta., Ann. Repts. for 1888, pp. 64–66 (1889); 1889, pp. 140–143 (1890); 1890 (1891); 1891 (1892).

[2] Me. Agr. Expt. Sta. Ann. Rept. for 1894 (1895).

1892. Six plots received no fertilizer treatments whatever. The remaining 30 plots received 10 different fertilizer treatments, the same treatment being applied to three plots in each case. The average annual results obtained from each fertilizer treatment are given in Table XXIX.

TABLE XXIX.—*Results of nine years of field work in the growing of various crops (1886–1894).*

Fertilizer.	Application, per acre.	Yield per acre (average of 3 plots).								
		1886	1887	1888 [1]	1889	1890 [1]	1891 [1]	1892 [1]	1893	1894
		Oats.	Oats.	Hay.	Fallow.	Peas.	Oats.	Peas.	Corn. [2]	Corn. [2]
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
No fertilizer	....	3,664	2,000	2,566	....	1,406	1,892	1,216	395	749
Dissolved bone back	400									
Potassium chloride	100	5,900	3,400	2,434	....	1,850	2,332	1,124	1,415	2,926
Ammonium sulphate	200									
Ground bone	360									
Potassium chloride	100	5,420	2,566	2,800	....	1,922	2,466	1,072	1,326	3,038
Ammonium sulphate	200									
Ground South Carolina rock	300									
Potassium chloride	100	5,052	3,100	2,566	....	1,762	1,936	860	1,076	2,631
Ammonium sulphate	200									
Stable manure	40,000	5,266	3,074	4,010	....	2,644	3,288	1,976	2,931	3,562
No fertilizer	....	3,968	2,400	1,634	....	1,618	2,068	1,180	366	978
Dissolved bone black	400	4,512	2,100	2,166	....	1,774	2,666	668	576	1,280
Do	400	4,906	2,634	2,066	....	1,978	2,668	736	1,486	2,532
Potassium chloride	100									
Dissolved bone black	200									
Potassium chloride	50	4,732	2,834	2,166	....	1,738	2,496	848	942	1,982
Ammonium sulphate	60									
Dissolved bone black	300									
Potassium chloride	100	5,640	3,500	1,766	....	1,694	2,700	1,092	967	2,598
Ammonium sulphate	120									
Dissolved bone black	400									
Potassium chloride	150	6,034	3,834	2,374	....	1,778	2,666	1,084	2,046	3,427
Ammonium sulphate	180									
Potassium chloride	100	4,500	2,700	2,234	....	1,422	2,000	1,180	905	1,879
Ammonium sulphate	200									

[1] No fertilizers. [2] Air dried.

In this experiment the plots treated with stable manure gave on the whole better results than any of the other plots. The plots receiving heavy applications of dissolved bone black in combination with potash and nitrogen carriers came next, followed by those treated with a mixture of bone meal, potash, and nitrogen. The plots treated with ground raw rock phosphate gave a lower average increase than the other phosphates, but produced in all but two instances a distinct gain over the plots fertilized with potash and nitrogen carriers alone.

While the applications of dissolved bone black (300 and 400 pounds per acre) employed in this experiment are considered comparatively heavy for such a soluble phosphate, an application of 300 pounds of ground raw rock is a light application for such a relatively insoluble material. Moreover, in describing this experiment there is nothing to indicate that the soil was well supplied with

organic matter, which would aid in rendering the less soluble phosphate more effective. The conditions, therefore, were much more favorable to the water soluble phosphates than to raw ground rock.

The results of the other long-time experiment published in this same report[1] cover a period of seven years. This second experiment was conducted on a larger scale than that just described and had two objects in view: First, to determine the possibility of maintaining soil fertility by the use of commercial fertilizers, and second, to determine the comparative value of raw rock phosphate and acid phosphate.

A 10-acre field, the soil of which was a clay loam and excellent grass land, was selected for this experiment, and divided into four plots of 2½ acres each. For two years (1888 and 1889) no fertilizers whatever were applied to any of the plots, grass being grown in order to determine their relative natural fertility. Fertilizers were applied only once during the seven years of the experiment (in 1890), so the results after that year show in a measure the residual effects of the various fertilizer treatments.

The results of this experiment are given below in Table XXX.

TABLE XXX.—*Results obtained on plots of two and one-half acres each, in the growing of various crops (1888–1894).*

Fertilizer.	Application per acre.	1888-89 Hay.[1]	1890[1] Barley and peas.	1891 Oats, Total.	1892 Barley, hay.	1893 Summer tilled.	1894 Oats, dry matter.[2]
	Loads.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Stable manure	20	2,542	2,208	3,818	3,444	....	1,894
	Pounds.						
Ground South Carolina rock	1,000						
Nitrate of soda	66	2,416	1,712	2,981	2,324	....	2,453
Ammonium sulphate	16						
Potassium chloride	100						
Acid phosphate	500						
Nitrate of soda	66	2,082	1,422	2,972	1,930	....	1,734
Ammonium sulphate	16						
Potassium chloride	100						
No manure	....	2,510	1,118	2,480	1,161	....	957

[1] Fertilizer applied in 1890 only.
[2] Oats were cut before maturing and used for silage.

The indications are that the plot which was afterwards treated with acid phosphate was naturally less fertile than the other plots of the experiment field. Contrary to what one would expect the raw rock phosphate was apparently as effective as acid phosphate during the first year of its application, yet the following year (if the apparent relative natural fertility of the two plots be taken into consideration) the acid-phosphate plot appeared to greater advantage

[1] Idem., p. 28–32.

since its yield nearly equaled that of the raw-rock plot. In 1892 and 1894 (particularly in the latter year), however, the plot receiving raw rock phosphate two and four years previously forged ahead very noticeably.

In 1896 Merrill[1] published the results of the box experiments begun by Ballentine[2] a number of years before and continued after the latter's death. The work was carried on still further, however, and all the results published by Merrill[3] in 1899.

This experiment was undertaken in order to determine the relative availability of various phosphates and also to test the ability of some of the common crops to obtain phosphoric acid from these different sources. The work was conducted in one of the greenhouses, and the plants grown in wooden boxes 14 inches square and 12 inches deep. The boxes were filled to within 1½ inches of the top with 120 pounds of sand. The sand was taken from a knoll near the river, at a depth of 3 or 4 feet, and was nearly free from organic matter. Traces of phosphoric acid were present. Before filling the boxes, the sand was carefully screened and mixed thoroughly with the various fertilizers.

Eighteen species of plants were grown, representing seven orders: (1) peas, horse beans, clover, and alfalfa (Leguminosæ); (2) turnips, rutabagas, cauliflower, and kohlrabi (Cruciferæ); (3) barley, oats, and timothy (Gramineæ); (4) tomatoes and potatoes (Solanaceæ); (5) carrots and parsnips (Umbelliferæ); (6) buckwheat (Polygonaceæ); and (7) sunflower (Compositæ).

It was planned to carry each plant through three periods of growth, but the clover would not mature in the time it took for the other plants to do so, hence only two crops were grown. The sunflower and buckwheat did not thrive under the conditions of the experiment; and, after a single trial, were replaced by carrots and parsnips, which were grown for the two following periods.

In each period 12 boxes were employed for each kind of plant. The boxes were divided into three sets of four each, the various phosphate treatments as well as the checks being run in triplicate.

No attempt was made at pollination, and since but few insects were present during the growth of the plants, the fruiting was very irregular. As soon as the plants seemed to have attained their maximum development they were harvested, dried, weighed, and the total amount of dried matter determined for each crop grown.

The phosphates used in this experiment were acid phosphate, Redonda phosphate (phosphate of iron and alumina) made largely citrate soluble by ignition, and Florida finely ground phosphate rock

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[1] Me. Agr. Exp. Sta. Ann. Rept. for 1895, p. 10–14 (1896).
[2] Me. Agr. Exp. Sta. Ann. Rept. for 1893 (1894).
[3] Me. Agr. Exp. Sta. Ann. Rept. for 1898 (1899).

(floats). These materials were added in such amounts that they each furnished 6.58 grams of phosphoric acid, an amount sufficient to add only 0.01 per cent of P_2O_5. In addition to the phosphate each fertilized box received 10 grams of sodium nitrate, 5 grams of potassium chloride, and 5 grams of magnesium sulphate. In the boxes where the Redonda was used 10 grams of calcium sulphate was also added.

The average production for a single period is shown in Table XXXI.

TABLE XXXI.—*Relative weights of dry matter obtained in box experiments with various phosphates.*

Crop.	Weight.	Phosphate treatment.	Crop.	Weight.
	Grams.			*Grams.*
Peas	167	Acid phosphate	Tomatoes	135
	122	Floats		92
	94	Redonda		79
	87	No phosphate		36
Horse beans	269	Acid phosphate	Potatoes	260
	128	Floats		187
	118	Redonda		156
	86	No phosphate		151
Clover	217	Acid phosphate	Carrots	214
	169	Floats		141
	126	Redonda		140
	83	No phosphate		135
Alfalfa	107	Acid phosphate	Parsnips	237
	97	Floats		151
	87	Redonda		155
	90	No phosphate		163
Turnips	222	Acid phosphate	Buckwheat	107
	202	Floats		54
	187	Redonda		51
	119	No phosphate		37
Rutabagas	152	Acid phosphate	Sunflowers	101
	145	Floats		14
	122	Redonda		15
	64	No phosphate		11
Cauliflower	176	Acid phosphate	Turnips (roots)	100
	167	Floats		70
	107	Redonda		90
	62	No phosphate		44
Kohlrabi	232	Acid phosphate	Rutabagas (roots)	62
	209	Floats		47
	172	Redonda		32
	130	No phosphate		16
Barley	338	Acid phosphate	Cauliflower	50
	171	Floats		19
	186	Redonda		....
	146	No phosphate		....
Corn	218	Acid phosphate	Kohlrabi	153
	85	Floats		129
	98	Redonda		92
	31	No phosphate		60
Potatoes (tubers)	185	Acid phosphate	Oats	662
	131	Floats		307
	140	Redonda		380
	115	No phosphate		319
Carrots (roots)	173	Acid phosphate	Timothy	410
	109	Floats		323
	113	Redonda		346
	102	No phosphate		353
Parsnips (roots)	196	Acid phosphate		
	115	Floats		
	114	Redonda		
	120	No phosphate		

While all the phosphate treatments appeared to be beneficial, in every case the boxes receiving acid phosphate gave greater yields than those treated with the Redonda or raw Florida rock. The gain was especially marked in the case of the Gramineæ family, three

members of which—barley, corn, and oats—yielded nearly double the amount produced by either the floats or Redonda phosphate.

The fact that the same quantity of phosphoric acid was applied in all forms and that this application was light for the relatively insoluble phosphates is distinctly unfavorable to these phosphates. Moreover, it is stated that the sand used in this experiment was nearly free from organic matter, which fact would also be unfavorable to the raw rock phosphate. It is not surprising, therefore, that greater yields were obtained from the use of the soluble phosphate in these experiments.

The results of both the field and greenhouse experiments conducted by the Maine Station indicate strongly that applications of raw rock phosphate increase the yields of many crops and that this material is more effective when applied liberally. The data, however, are insufficient to be conclusive as to the relative merits of raw rock and acid phosphate.

MARYLAND.

The first work conducted by the Maryland station to test the fertilizer value of the relatively insoluble phosphates consisted of several experiments[1] on corn, wheat, sweet potatoes, and tomatoes, but in all these experiments the natural phosphates employed were guanos from islands in the Caribbean Sea. According to the analyses of these guanos they contained a certain amount of available (so called) phosphoric acid, and in some instances a small percentage of nitrogen, so it is hardly fair to place them in the same class with the amorphous phosphates of Florida, South Carolina, and Tennessee. For this reason the results of these experiments are not included in this paper.

The results of five years' work in testing the relative values of various carriers of lime were published by the station in 1906.[2] While finely ground South Carolina rock was used on one of the plots, no comparison can be made of its value with that of acid phosphate in this experiment since all the plots, with the exception of the checks received in addition to the lime carriers applications of a complete fertilizer. Under these conditions lime in the form of oxide, hydrate or carbonate produced yields as great as that obtained from lime combined with phosphoric acid in ground rock phosphate. It is worthy of note, however, that the plot receiving ground rock phosphate in addition to a complete fertilizer produced greater yields than the plot treated with complete fertilizer alone.

The results of work carried on for 12 consecutive years with various kinds of phosphate were published by the Maryland station in

[1] Md. Agr. Expt. Sta., Bul. No. 5 (1889); Special Bul. (Fair edition) (1889); Buls. Nos. 10 (1890); 14 (1891).

[2] Md. Agr. Expt. Sta., Bul. No. 110 (1906).

1907.[1] These experiments had several objects in view but were conducted chiefly to test the relative fertilizer value of the soluble and the relatively insoluble phosphates on corn, wheat, and hay.

The field used is said to be fairly level, well drained, and quite uniform throughout. The soil was moderately stiff clay. The history of the cropping of this field before the experiment was undertaken is as follows:

In 1888 the land grew a poor crop of weeds and grass which was plowed down. The land was then sown to wheat which was harvested in 1889; in 1890 and 1891 the field was in grass, and in 1892 corn was planted. The land was fallowed in 1893, but in 1894 it was again planted to wheat in which both timothy and clover were sown.

In 1895[2] the field was divided into 22 plots of one-tenth acre each and planted to corn, crimson clover being sown subsequently in the corn on plots 1 to 12, and rye on plots 18 to 22. These latter crops were plowed under the following spring. In 1896, 1897, and 1898[3] corn was again grown under the same conditions. In 1899 a crop of wheat was harvested followed by hay in 1900 and 1901. In 1902 and 1903 corn was again grown followed by wheat in 1904 and hay in 1905.

The various phosphates were applied in such quantities as to furnish equal amounts of phosphoric acid to the soil. It appears that the phosphate applications were made every year except in 1899, 1900, 1901, and 1905 when wheat and hay were the crops grown.

There were four check (no phosphate) plots employed in this experiment, on two of which a green crop (rye or clover) was turned under subsequent to the growing of corn. In the tables given below only the average of these four plots is reported. Three plots each were treated with the following phosphates in quantities supplying 150 pounds of P_2O_5 per acre, raw bone meal, basic slag, ground South Carolina raw rock and Florida soft phosphate. Two each of these plots had a green crop turned under in six out of the 12 years of the experiment, in order to study the effect of decaying organic matter on the availability of these relatively insoluble phosphates. In the following tables the average of the three plots is taken in each instance, although in some cases the organic matter present apparently increased the effectiveness of the phosphate treatment.

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[2] Md. Agr. Expt. Sta., Bul. No. 114 (1907).
[3] Md. Agr. Expt. Sta., 8th Ann. Rept., p. 226 (1895).
[3] The corn crop in 1898 was a failure.

TABLE XXXII.—*Yields of corn (grain and fodder) per acre obtained (1895–1906).*

Fertilizer.	Application per acre.	1895		1896		1897		1902		1903		1906		Average of 6 crops of grain.	Average of 5 crops of fodder.
		Grain.	Fodder.	Grain.	Fodder.	Grain.	Fodder.	Grain.	Fodder.	Grain.	Fodder.	Grain.	Fodder.		
	Pounds.	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*
Double superphosphate	319	46.0	2,860	40.3	2,100	57.9	3,020	45.7	2,600	17.6	750	39.9	2,000	41.2	2,516
Dissolved bone black	735	38.7	2,700	37.4	2,200	51.1	2,930	46.4	2,600	21.8	785	46.1	2,300	40.3	2,546
Dissolved South Carolina rock	1,000	39.0	2,400	35.8	2,340	43.6	2,810	43.6	2,650	16.2	....	44.6	2,050	37.1	2,450
Reverted phosphate of lime	370	35.8	2,420	37.0	2,060	47.7	2,920	46.4	2,650	29.3	....	45.8	2,150	40.3	2,400
Nothing [1]	....	43.4	2,480	41.9	2,130	46.2	2,778	37.7	2,350	35.4	1,847	41.3	2,088	40.9	2,365
Reverted iron and aluminum phosphate	370	45.4	2,940	43.2	2,400	64.9	3,330	50.0	2,950	18.0	....	42.7	2,200	44.0	2,764
Bone black	514	36.9	2,340	41.6	2,160	58.1	3,070	43.2	2,550	17.8	....	34.1	1,700	38.9	2,364
Raw bone meal [2]	667	44.8	2,460	44.2	2,400	54.3	3,046	46.4	3,067	21.5	1,400	26.0	1,517	39.5	2,498
Slag phosphate [2]	920	43.7	2,340	43.9	2,713	49.8	2,927	44.0	3,000	22.6	1,050	30.6	1,633	39.1	2,523
Ground South Carolina rock [2]	530	45.2	2,447	43.8	2,227	43.7	2,920	42.5	2,707	23.6	1,367	39.5	2,150	39.7	2,490
Florida soft phosphate [2]	560	46.7	2,547	40.7	1,773	44.6	2,957	46.7	3,167	35.4	1,967	41.2	2,050	42.6	2,499

[1] The yields of the checks are the average of four plots, two of which had a green crop turned under every year corn was grown.
[2] The yields are the average obtained on three plots, two of which had a green crop turned under.

TABLE XXXIII.—*Yields*[1] *of wheat and hay per acre obtained (1895–1906).*

Fertilizer.	Application per acre.[2]	1899 Wheat. Grain.	1899 Wheat. Straw.	1900 Hay.	1901 Hay.	1904 Wheat. Grain.	1904 Wheat. Straw.	1905 Hay.	Average yields. Wheat. Grain.	Average yields. Wheat. Straw.	Average yields. Hay.
	Pounds.	*Bushels.*	*Pounds.*	*Pounds.*	*Pounds.*	*Bushels.*	*Pounds.*	*Pounds.*	*Bushels.*	*Pounds.*	*Pounds.*
Double superphosphate	319	36.0	4,140	3,900	4,300	12.2	1,070	2,400	24.1	2,605	3,533
Dissolved bone black	735	37.1	4,375	4,200	4,310	12.0	775	2,500	24.6	2,575	3,670
Dissolved South Carolina rock	1,000	37.0	2,930	4,950	4,050	12.3	760	2,400	24.6	1,845	3,800
Reverted phosphate of lime	370	31.6	3,550	4,250	4,650	12.8	1,030	3,400	22.2	2,290	4,100
Nothing	....	21.8	2,601	3,838	3,812	3.1	340	850	12.5	1,471	2,833
Reverted iron and aluminum phosphate	370	34.6	3,170	4,800	6,450	12.2	1,070	2,900	23.4	2,120	4,717
Bone black	514	25.6	3,415	4,000	4,350	9.3	590	2,700	17.5	2,003	3,683
Raw bone meal	667	35.0	3,903	3,867	4,200	12.3	980	3,016	23.7	2,442	3,694
Slag phosphate	920	36.2	4,195	3,550	4,517	9.3	775	3,633	22.8	2,485	3,900
Ground South Carolina rock	530	31.5	3,509	4,217	4,533	8.7	777	2,966	20.1	2,143	3,905
Florida soft phosphate	560	30.0	3,134	4,050	4,517	9.7	643	2,760	19.9	1,886	3,776

[1] The yield of the check is the average of four plots, two of which had a green crop turned under; and the yields of the treated plots are the average of three plots, two of which had a green crop turned under in connection with the phosphates.
[2] Phosphates were applied in 1895, 1896, 1897, 1898, 1900, 1901, 1902, 1903, 1905, 1906.

The results on corn given in Table XXXII are rather inconclusive, even though they represent the crops of six years. The average production of the no-phosphate plots was in many instances greater than that of the plots receiving phosphate treatments. Only in the cases of the plots treated with reverted phosphate of iron and aluminum were there fairly consistent increases obtained over the check plots. In 1903 the average yield of the check plots exceeded that of any of the others except the Florida soft phosphate plots and equaled the average yield of these.

The yields of the various soluble phosphate plots were very inconsistent. For instance, the plot treated with double acid phosphate gave on the average an increase in yield over and above the no-phosphate plots, yet the plot treated with dissolved South Carolina rock (ordinary acid phosphate), which was applied in such quantities as to furnish the same amount of phosphoric acid, gave a yield considerably below the average of the check plots.

The results obtained on the hay crop (Table XXXIII), however, were more consistent. With the exception of the first crop of the dissolved South Carolina rock plot, the yields from the less soluble phosphate plots were greater than from the water soluble phosphate plots, and in nearly every instance the yields of the treated plots were considerably greater than those of the checks. Here, again, the reverted phosphate of iron and aluminum gave the highest yields.

Although the conditions of this experiment were apparently more favorable to the soluble phosphates the results indicate that for corn and hay the relatively insoluble phosphates of iron and aluminum in a very finely divided or precipitated condition, were more effective than the former.

In the case of the two crops of wheat grown on these same plots the opposite results were obtained (Table XXXIII). The yields of the soluble phosphate plots in most instances exceeded the yields of the relatively insoluble phosphate plots quite appreciably, and all the treated plots gave considerable increases in yield over the check plots.

Regarding the influence of decaying organic matter in the soil, the turning under of rye seemed to increase somewhat the effectiveness of the insoluble phosphates, but the plots on which clover was grown and subsequently turned gave on the average smaller yields than similar plots receiving no organic matter.

In studying the results of these experiments two questions naturally arise. First, how uniform was the soil of the various plots, and, second, what would have been the effect of applications of lime?

Another five-year experiment undertaken by the Maryland station some time after the one just described and discussed, gives consideration to these points. In this later experiment an attempt was

made to determine the relative natural fertility of the various plots on the experimental field by uniform cultivation, and the growing of wheat and hay for three years preceding the application of the phosphates.

The yields of the various plots during these three years are given in Table XXXIV.

TABLE XXXIV.—*Relative productive capacity of plots when receiving uniform treatment.*

Plot number.	Wheat, 1899.		Hay.		Total of 3 crops.	Average yearly yield.
	Grain.	Straw.	1900	1901		
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	1,535	2,800	4,050	4,010	12,395	4,132
2	1,415	2,630	3,500	3,150	10,695	3,565
3	1,835	3,565	3,600	3,900	12,900	4,300
4	2,130	4,070	4,500	3,750	14,450	4,817
5	2,120	3,980	4,550	4,050	14,700	4,900
6	2,100	4,300	3,450	3,750	13,600	4,533
7	2,190	4,310	4,350	4,100	14,950	4,983
8	2,165	4,100	2,500	4,400	13,165	4,388

The figures given in Table XXXIV indicate strongly that this field was not of uniform fertility. They show how the relative yields of similarly treated plots may vary from year to year independent of fertilizer treatment, thus making it not only unwise but well nigh impossible to draw final conclusions from field work covering only a short period of time.

The yields of the same plots after treatment with the various phosphates are given in Table XXXV. Besides introducing other varieties of phosphates into this experiment, the effect of liming on the soil was studied by employing two soluble phosphate plots, one of which received in addition to acid phosphate a liberal application of lime.

TABLE XXXV.—*Yields of plots (reduced to yields per acre) when fertilized (1902–1906).*

Plot number.	Phosphate treatment, 150 pounds P_2O_5 per acre in the following forms.	1902		1903		1904		1905	1906		Total yield of 5 crops.	Average yield.
		Corn.		Corn.		Wheat.		Hay.	Corn.			
		Grain.	Fodder.	Grain.	Fodder.	Grain.	Straw.		Grain.	Fodder.		
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	South Carolina phosphate rock....	3,500	3,000	2,410	1,550	350	400	1,600	3,485	3,000	19,235	3,847
2	Dissolved South Carolina rock.....	3,190	3,000	2,185	1,450	660	740	2,450	2,960	2,500	19,135	3,827
3	Dissolved South Carolina rock and lime..........................	3,800	3,050	2,690	1,600	415	485	3,000	2,485	2,000	19,535	3,907
4	Nothing..........................	3,670	3,050	3,570	2,300	245	555	1,950	3,000	2,250	20,590	4,118
5	Tennessee phosphate..............	4,050	3,000	3,910	2,500	550	600	3,200	3,660	2,650	24,120	4,824
6	Florida soft phosphate............	3,390	3,300	4,355	2,850	665	1,335	3,450	3,920	2,500	25,765	5,153
7	Virginia phosphate................	3,250	2,300	4,875	3,250	600	900	4,500	3,800	2,900	26,385	5,277
8	Precipitated phosphate...........	3,300	2,800	4,195	2,200	840	1,310	4,200	3,240	2,400	24,485	4,897

In order to see at a glance the apparent relative values of the various phosphates used in this experiment, the Maryland station compiled a table in which the yields given in Tables XXXIV and XXXV were reduced to a percentage basis, taking the yield of the Virginia phosphate plot as 100. The results are given in Table XXXVI. It will be noted that the average production of the different plots after the application of the phosphates was less than before the treatments, but since the greatest decrease in yield was on the check plots, it is assumed that the phosphates had a beneficial effect.

The figures in the column headed "Relative increase" represent the average relative increases of the various phosphate plots over the check plot.

TABLE XXXVI.—*Relative yields and average influence of different forms of phosphoric acid, expressed in percentages.*

Phosphate treatment, 150 pounds P_2O_5 per acre, in the following forms:	Rate of yield before experiment.	Rate of yield during experiment.	Difference.	Relative increase.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Ground South Carolina rock	83	73	−10	10
Dissolved South Carolina rock	72	72	0	20
Dissolved South Carolina rock and lime	86	74	−12	8
Check (no phosphate)	97	77	−20	0
Ground Tennessee rock	98	91	− 6	14
Ground Florida rock	91	98	+ 7	27
Ground Virginia rock	100	100	0	20
Precipitated phosphate	88	93	+ 5	25

Apparently the greatest effect was produced by the Florida soft phosphate and the precipitated phosphate treatments. The Virginia phosphate (which, it is said, was largely a phosphate of aluminum) and the acid phosphate (without lime) came next with the same relative increase. Contrary to popular belief the application of lime in connection with acid phosphate did not in this experiment appear to be beneficial.

The Maryland station results as a whole may be said to indicate that applications of the relatively insoluble phosphates in a finely divided or precipitated condition increase crop yields as effectively in some instances as the more soluble phosphates.

MASSACHUSETTS.

In 1890 the Massachusetts station undertook an experiment[1] to compare the relative fertilizer merits of acid phosphate (dissolved bone black) and some of the less soluble phosphates when the various forms were applied in quantities representing at that time equal money values.

The field selected for this experiment was quite level and had been used as a meadow up to 1887. The soil was a fair sandy loam, but

[1] Mass. Agr. Expt. Sta., 8th, 9th, 10th, and 11th Ann. Repts. Hatch Agr. Expt. Sta., 14th Ann. Rept. (1902).

said to be well worn. In order to exhaust the field still further of its natural fertility, corn, Hungarian hay, and legumes were grown in 1888 and 1889 without the application of any fertilizer whatever, but no attempt was made to determine whether or not the field was uniform.

In the spring of 1890 the plots (1/6 acre each) were laid out and each one furnished annually with what were thought to be optimum quantities of potash and nitrogen. The following applications of phosphates were made to the various plots annually for four years:

Plot No. 1: Basic (phosphatic) slag........ (19.04 per cent P_2O_5) =127 pounds
2: Mona guano .... (21.88 per cent P_2O_5) =128 pounds
3: Ground Florida rock phosphate... (21.72 per cent P_2O_5) =129 pounds
4: Ground South Carolina phosphate.. (27.57 per cent P_2O_5) =131 pounds
5: Dissolved bone black............ (15.82 per cent P_2O_5) = 78 pounds

In 1894 the phosphate applications were discontinued in order to study their residual effects but the potash and nitrogen applications were increased 50 per cent. A check or no phosphate plot was introduced in 1895, and the experiment continued until 1902 (12 years).

In Table XXXVII the yields of the various crops during the entire period of the experiment are given. Apparently no details of the corn crop of 1898, and the oat crop of 1899, have been published, and the yields of the check plot during 1895 and 1896 could not be found in the records.

TABLE XXXVII.—*Yields per acre of various crops during twelve years of experiment (1890–1901).*

Fertilizer.	Annual[1] application per acre.	1890 Potatoes.	1891 Wheat.	1892 Serradella.	1893 Corn.	1894 Barley.	1895 Rye.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Basic slag	762	9,600	2,280	24,420	9,960	2,940	4,170
Mona guano	768	8,490	2,040	20,460	8,286	2,430	3,780
Ground Florida rock	774	9,000	1,290	16,500	8,082	1,740	2,298
Ground South Carolina rock	786	10,980	2,280	18,660	8,814	2,760	4,554
Dissolved bone black	468	12,720	2,430	17,520	7,932	2,340	3,750
No phosphate	....	....	....	....	....	....	Not given

Fertilizer.	Annual[1] application per acre.	1896 Soy beans (beans).	1897 Turnips (roots).	1898 Corn.	1899 Oats.	1900 Cabbage.[2]	1901 Oats (grain).
	Pounds.	*Pounds.*	*Pounds.*			*Pounds.*	*Bushels.*
Basic slag	762	1,524	11,220	(3)	(3)	1,980	100
Mona guano	768	1,398	21,930	(3)	(3)	1,500	84
Ground Florida rock	774	1,572	4,920	(3)	(3)	60	67
Ground South Carolina rock	786	1,512	11,790	(3)	(3)	3,300	95
Dissolved bone black	468	1,482	9,714	(3)	(3)	1,560	79
No phosphate	....	Not given	4,980	(3)	(3)	48	87

[1] Phosphates applied during the first four years only.
[2] The weights given represent cabbages which weighed over 2½ pounds.
[3] No detailed yields given.

It will be seen that while dissolved bone black led for the first two years, during the remainder of the experiment several of the relatively insoluble phosphates forged ahead, phosphatic slag being first, South Carolina floats second, and Mona guano third. Florida ground rock phosphate, however, gave relatively poor yields when compared with the plot treated with South Carolina floats.

In Table XXXVIII the average relative rank of the various plots from the beginning of the experiment, until it was discontinued in 1902, are expressed on a percentage basis.

TABLE XXXVIII.—*Average relative rank of the plots treated with various phosphates*[1] *(equal money values) during the 12 years*[2] *of the experiment.*

Treatment.	Per cent.
Basic (phosphatic) slag	100.0
Ground South Carolina rock	92.6
Dissolved bone black	89.7
Mona guano	87.3
Florida phosphate rock	71.1
No phosphate (6 years)	55.4

[1] No phosphates applied after the third year.
[2] The crop of Swedish turnips grown in 1897 is not included, since it was damaged by disease.

While the basic slag and ground South Carolina phosphate plots led all the rest in this experiment, the dissolved bone-black plot was not far behind.

Brooks[1] considers that the phosphates in this experiment were applied in a very irrational manner and in a way favorable to the relatively insoluble varieties, but even under these conditions he concludes that the data do not prove that the less soluble were more effective than the readily soluble phosphates since the yields from the Mona guano and Florida phosphate plots (particularly the latter) were materially less than that of the acid phosphate plot.

While the writers feel that the data obtained are hardly sufficiently consistent to warrant a definite conclusion regarding the relative merits of the various phosphate carriers, nevertheless they are of the opinion that the method of applying phosphates in this experiment was considerably more logical from an economic standpoint than that employed in the subsequent experiment of the Massachusetts station upon which Brooks lays much greater stress.

In 1897 a second experiment[2] was undertaken by the Massachusetts station to test the fertilizer value of various phosphates when they were applied in such amounts as to furnish equal quantities of phosphoric acid to the soil.

[1] Mass. Agr. Expt. Sta., Bul. No. 163, pp. 147–148 (1915).
[2] Hatch Agr. Expt. Sta., 10th Ann. Rept. (1898).

A summary and discussion of this experiment after 18 years' work was published by Brooks[1] in 1915.

The field selected for this experiment was fairly level, but while the soil as a whole was a medium silt loam, the plots varied somewhat in physical character. Moreover, the fertility of the various plots (as determined by a crop of corn grown the year previous to the application of fertilizer) was apparently not uniform. The field had been in grass for a number of years preceding the experiment, and had received annually moderate top dressings of chemical fertilizers. In 1896, the field was plowed, divided into 13 plots of $\frac{1}{8}$ acre each, and planted to corn without the addition of any fertilizer whatever, in order to determine the relative natural fertility of the various plots. The corn was cut green and weighed. Apparently there has been some confusion in the statement of the yields of corn obtained in this preliminary test, for in Public Document No. 33,[2] published shortly after the experiment was begun the yields obtained on plots 1 to 13, inclusive, are in the reverse order from those given in Brooks's summary of this experiment published in Bulletin No. 162. On account of this confusion the yields obtained in this preliminary test can not very well be taken into consideration in figuring the relative efficiency of the phosphate treatments.

The various phosphates to be tested were applied in the spring of 1897, together with liberal amounts of potash and nitrogen. In 1898, and again in 1914, all plots were treated with hydrated lime at the rate of 1 ton per acre, which was spread upon the plowed land and harrowed in. The annual application of fertilizer materials varied somewhat, the most important change being an increase of 50 per cent in the nitrate nitrogen and the actual potash in 1901. Since that date the annual rate of application per acre has been 91.2 pounds of nitrogen, 152 pounds of potash, and 96 pounds of phosphoric acid.

In order that the less soluble phosphates might have their full effect "a stock of organic matter was maintained in the soil by turning under heavy crops as follows: Winter rye in 1901, buckwheat in 1912, and rye in 1913, and by introducing grasses and clovers, 1905 to 1907, and turning under a heavy growth of grass in 1908."

Hopkins[3] considers that the supply of organic matter thus furnished was inadequate to meet the requirements of the crops and receive full benefit from the raw rock phosphate treatments.

The following table taken from Bulletin No. 153, of the Massachusetts station gives the increases in yield of various crops (over

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[1] Mass. Agr. Expt. Sta., Bul. No. 162 (1915)
[2] Mass. Agr. Expt. Sta., 10th Ann. Rept., p. 17 (1898).
[3] Ill. Agr. Expt. Sta., Circ. No. 186, p. 13 (1916).

and above the check plots) obtained from plots treated with the different types of phosphates up to the close of 1914.

In reporting these results Brooks discarded the yields obtained during the first two years of the experiment on the assumption that the difference in the natural fertility of the plots would be less strongly marked after two years of fertilization. It might be said, however, that if the same plan had been followed in the earlier experiment where equal money values of the various phosphates were applied the average results would have been even more favorable to the less soluble phosphates than reported.

In comparing the crop yields in this later experiment each plot was compared with the check plots between which it lay and these checks were given a weight inversely proportional to their distance from the plot for which they served as a basis of comparison.

The validity of such a method of comparison is based on the assumption that the variations in the fertility of a field are fairly regular. Other investigators consider that a comparison of the average yield of all check plots with each treatment is a much fairer basis on which to compute differences in fertilizer values.

TABLE XXXIX.—*Average increase per acre in corps produced on plots treated with different classes of phosphates (1899–1914).*

Fertilizer.	Corn, 3 years, 1899, 1913, 1914.		Hay, 2 years, 1906, 1907.			Onions, 2 years, 1901, 1902.		Cabbage, 2 years, 1903, 1908.
	Grain.	Stover.	Hay.	Rowen.	Total.	Sound.	Scallions.	
	Bush.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Bush.*	*Bush.*	*Lbs.*
Natural mineral phosphates	−1.06	318.87	398.30	−131.00	267.30	−30.60	10.76	9,817.50
Basic slag and bone meals	8.03	905.50	615.55	97.33	712.88	143.60	−19.23	21,026.00
Dissolved phosphates	9.96	651.11	753.33	350.67	1,104.00	136.73	−12.56	18,758.60

Fertilizer.	Oat hay, 1 year, 1900.	Hungarian hay, 1 year, 1900.	Ensilage corn, 1 year, 1904.	Soy beans, 1 year, 1910.		Potatoes, 1 year, 1910.		Oat and alfalfa hay, 1 year, 1911.	Alfalfa hay, 1 year, 1911.
				Grain.	Straw.	Marketable.	Total.		
	Lbs.	*Lbs.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Bush.*	*Lbs.*	*Lbs.*
Natural mineral phosphates	231.70	166.70	−1,638.70	0.77	290.56	−10.70	−8.30	80.00	91.70
Basic slag and bone meals	1,324.40	−222.23	7,608.90	4.09	794.67	16.40	18.90	1,626.67	244.40
Dissolved phosphates	1,520.00	−253.30	7,361.30	3.87	776.00	26.90	29.50	1,560.00	73.30

It will be seen by dividing the phosphates into classes and taking the average yield of each class, as Brooks has done in his summary, the soluble phosphate plots on the whole surpassed all the other phosphates. Next in order came the so-called available phosphates, consisting of raw bone, steamed bone, and basic slag, and finally

the lowest average yields were obtained from the plots treated with the natural phosphates of Arkansas, Florida, Tennessee, and South Carolina.

It seems questionable to the writers, however, if this method of grouping the various phosphates is altogether fair. By referring to Table XL it will be seen that the yields from the Florida soft phosphate plot were in many instances poor when the yields from the other raw-rock plots, particularly the South Carolina rock plot, were good. By grouping Florida soft phosphate with the South Carolina and Tennessee phosphates the average yield for raw rock is seriously affected.

Neither does the placing of dissolved bone meal, acid phosphate, and dissolved bone black in one group appear quite fair, since the first-mentioned material contains appreciable quantities of nitrogen, and in nearly every instance the yield of this plot exceeded the other soluble phosphate plots by a considerable margin.

In order that the reader may obtain a clearer idea of the value of each fertilizer treatment the writers have compiled the following table from the reports of this work as given from year to year during the entire period of the experiment. Full details of yields, however, are not given in the reports for the years 1898, 1899, 1900, 1905, 1908, 1909, 1911, and 1912.

TABLE XL.—*Results of 18 years' work,*[1] *in the growing of various crops on 13 plots of one-eighth acre each (1897–1914).*

Plot number.	Fertilizer.	Application per acre.	1897 Corn, yield per acre.	1901 Onions, yield per acre.	1902 Onions, yield per acre.	1903 Cabbage, yield per acre.	1904 Green corn, yield per acre.	1906 Hay, yield per acre.	1907 Hay, yield per acre.	1910 Potatoes, yield per acre.	1913 Corn yield, gain per acre.	1914 Corn, yield per acre.
		Pounds.	*Bushels.*	*Bushels.*	*Bushels.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Bushels.*	*Bushels.*	*Bushels.*
1	None	....	58.5	279	196	13,400	41,000	6,600	8,400	286	....	79.6
2	Arkansas phosphate	376	56.5	222	102	20,920	40,720	7,520	8,800	289	−1.9	74.8
3	South Carolina rock phosphate	376	64.5	235	122	36,520	40,496	7,440	8,480	265	−2.2	80.5
4	Florida soft phosphate	364	72.5	151	52	25,680	28,240	7,600	8,480	235	−0.2	75.6
5	Basic slag	538	62.0	252	252	37,960	36,440	7,600	8,360	246	6.1	76.8
6	Tennessee phosphate	296	67.8	206	45	30,880	32,120	7,120	8,040	236	1.9	78.0
7	None	....	64.3	141	51	14,520	32,344	7,000	8,160	244	....	74.8
8	Dissolved bone black	522	61.8	210	174	39,912	30,080	6,960	9,200	248	3.5	84.2
9	Raw bone meal	404	67.3	252	301	44,240	45,800	7,120	9,240	259	7.3	85.6
10	Dissolved bone meal	432	63.3	213	389	42,080	41,840	7,520	9,160	264	14.3	77.3
11	Steamed bone meal	380	50.3	188	244	36,920	28,400	7,120	8,320	262	15.2	80.5
12	Acid phosphate	500	62.8	188	159	30,320	29,040	7,080	8,040	257	10.6	74.6
13	None	....	67.3	123	26	8,520	20,240	6,560	7,240	215	....	51.9

[1] For the years 1898, 1899, 1900, 1905, 1908, 1909, 1911, and 1912 very incomplete data are given, and in no case are the results obtained on plots treated with raw rock phosphate reported.

By studying the detailed yields obtained during the 18 years of this experiment it will be seen that the method of computing fertilizer values used by Brooks, namely, comparison of the treatments with the nearest check plots, is distinctly favorable to the plots receiving soluble and so-called available phosphates, since these plots lie closer to the check giving lower yields. As far as the figures are complete in detail, the plots treated with South Carolina and Tennessee phosphate exceeded in yield those treated with acid phosphate in eight out of nine and six out of nine cases, respectively.

In view of the fact that the difference between the yields of the check plots in this experiment are in many instances much greater than the differences between the yields of the treated plots, the drawing of rigid conclusions concerning the value of the different types of phosphates hardly seems warranted. Neither of the two long-time field experiments conducted by the Massachusetts Station appear to warrant a definite conclusion concerning the relative merits of raw rock and acid phosphate. Under the conditions of the first experiment (where equal money values of the two forms of phosphoric acid were applied) the results indicate that raw rock was more effective than acid phosphate. In the second experiment (where phosphoric acid was applied in various forms at the same rate) the results may be interpreted as favorable or unfavorable to raw rock phosphate depending on the method employed in comparing the yields with those of the check plots.

MISSISSIPPI.

The first field work with raw rock phosphate conducted by the Mississippi station was described by Ferris[1] in 1906. Owing to the short duration (one year),[2] this experiment as well as six others[3] which were conducted for periods of from one to four years are not considered in detail in this bulletin.

In 1911 Ferris[4] reported the results of six years' work with fertilizers on cotton at the McNeill branch station, and early in 1912[5] gave the results obtained during six years of field work on corn and cotton.

The fields on which these experiments were conducted are described as nearly level and as uniform as possible. The soil, it is said, was typical of the pine lands in south Mississippi. The plots were one-twentieth acre in size, and the treatments on each crop were

[1] Miss. Agr. Expt. Sta., Bul. No. 94 (1906).

[2] It is stated that this experiment was continued for four years but details are given for one year only.

[3] Miss. Agr. Expt. Sta., Buls. Nos. 110 (1908); 122 (1909); 155 (1911); 158 (1912); 161 (1913); 169 (1914).

[4] Miss. Agr. Expt. Sta., Bul. No. 155 (1911).

[5] Miss. Agr. Expt. Sta., Bul. No. 158 (1912).

made in triplicate, the plots being so distributed as to reduce to a minimum the errors due to inequalities in the soil. Each plot received annually the same kind and quantity of fertilizer material.

In the case of the corn, cowpeas were grown as a catch crop in the field. It is not stated whether this latter crop was turned under or not. The results of these experiments are given in Tables XLI and XLII.

TABLE XLI.—*Yields of shucked ears of corn (per acre) obtained at McNeill branch station for 1907–1911, inclusive.*

Plot number.	Fertilizer.	Application per acre.	Yield per acre of shucked ears.				
			1906	1907	1908	1910	1911[1]
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	Check	....	1,051	153	66	560	793
2	Cottonseed meal	100	1,699	740	446	860	1,406
3	Acid phosphate	100	2,037	1,380	846	840	1,880
4	Kainit	100	1,339	713	173	520	1,072
5	Cottonseed meal Acid phosphate	100 100	1,886	1,200	1,073	1,220	1,792
7	Cottonseed meal Acid phosphate	200 100	1,944	1,466	1,200	1,360	2,000
	Cottonseed meal Acid phosphate	100 200	1,807	1,306	860	1,380	1,712
	Cottonseed meal Ground rock phosphate	100 100	....	....	1,073	1,400	....
	Raw ground bone	100	2,094	1,526	....	....	....
12	Cottonseed meal Reverted phosphate	100 400	1,900	1,473	....	....	2,020

[1] Fertilizer applications doubled in 1911.

NOTE.—Crop of 1909 was a failure.

TABLE XLII.—*Yields of seed cotton per acre obtained at McNeill branch station for 1907–1911, inclusive.*

Plot number.	Fertilizer.	Application per acre.	Yield per acre of seed cotton.					
			1906	1907	1908	1909	1910	1911[1]
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1	Check	....	480	220	110	153	20	30
2	Cottonseed meal	100	760	436	376	400	90	63
3	Acid phosphate	100	800	514	744	480	366	166
4	Kainit	100	620	300	274	186	34	8
5	Cottonseed meal Acid phosphate	100 100	1,060	616	644	513	326	292
7	Cottonseed meal Acid phosphate	200 100	1,040	756	684	620	306	370
8	Cottonseed meal Acid phosphate	100 200	1,000	666	636	480	254	340
10	Cottonseed meal Ground rock phosphate	100 100	840	510	....	520	....	220
11	Raw ground bone	100	....	....	720	....	....	....
12	Cottonseed meal Reverted phosphate	100 400	....	....	680	....	460	....

[1] All applications of fertilizer doubled in 1911.

In these experiments the ground raw rock phosphate was applied in such relatively small amounts that little effect could be expected from its use. The yields of corn obtained from the raw rock cottonseed meal plot in 1908 and 1910, however, compare very favorably

with the yields from the plots receiving mixtures of acid phosphate and cottonseed meal, and in every case the phosphate-cottonseed-meal mixtures gave substantially greater yields than the cottonseed meal alone.

The yields obtained in the cotton experiment, however, were more favorable to acid phosphate than to the raw rock, but the plots treated with the latter phosphate mixed with cottonseed meal gave a greater yield than those treated with cottonseed meal alone.

It may be said that while these experiments give a very limited amount of data on the fertilizer value of raw rock phosphate they indicate that even light applications of this material when supplemented with cottonseed meal may produce substantial increases in the yield of corn and cotton.

Of the nine field experiments with raw rock phosphate conducted by the Mississippi station only two were continued beyond four years. In these two the applications of the ground raw rock were so light that results can hardly be considered indicative of the value of this material. In practically all of the experiments, however, plots receiving raw rock phosphate, either alone or in combination with other fertilizer materials, have shown substantial increases over the check plots with which they were directly comparable.

MISSOURI.

The Missouri station advised the use of raw rock phosphate in 1905[1] and 1910,[2] but it was not until 1914 that any data obtained from field work was published by this station.

In an experiment described by Miller, Hutchison, Douglass, and Hudelson,[3] a study was made of the effect of various fertilizer treatments on both drained and undrained land in a four-year rotation of corn, oats, wheat, and cowpeas (with cowpeas grown and turned as a catch crop between the regular crops of the rotation).

The field selected for this experiment was a 10-acre tract of very level poorly drained prairie land lying one-half mile west of Vandalia. The soil was a dark-gray silt loam 7 to 9 inches in depth underlain by a silty clay. The field was divided into two equal parts and one half tiled and the other half left untiled. Each half was then divided into seven plots of seven-tenths acre each, running crosswise of the drained and undrained areas. The corresponding plots in each area were then treated as follows: Manure at the rate of 8 tons per acre, and raw rock phosphate at the rate of 600 pounds per acre every four years before corn, bone meal 150 pounds per acre, and potassium chloride 50 pounds per acre, twice during a rotation.

[1] Mo. Agr. Expt. Sta., Circular of Information No. 22, p. 25 (1905).
[2] Mo. Agr. Expt. Sta., Bul. No. 84, p. 33 (1910) ; Bul. No. 86, p. 91 (1910).
[3] Mo. Agr. Expt. Sta., Bul. No. 118, 443–475 (1914).

Lime was also applied at the rate of 2,000 pounds per acre every four years. The first fertilizer applications were made in 1908, but in 1907 a crop of cowpeas was grown on the entire tract in order to compare the drained and undrained areas.

The results of five years' work with the fertilizer treatments mentioned above are given in Table XLIII.

TABLE XLIII.—*Yields of corn, oats, wheat, and cowpeas obtained on tiled and untiled land at Vandalia, Mo. (1908–1912).*

Fertilizer.	Application per acre.	Yield of various crops per acre.					
		Corn (1908).		Oats (1909).		Wheat (1910).	
		Drained.	Undrained.	Drained.	Undrained.	Drained.	Undrained.
Manure Rock phosphate Legume	*Tons.* [1] 8 *Pounds.* [1] 600	*Bushels.* 33.7	*Bushels.* 31.6	*Bushels.* 63.0	*Bushels.* 54.8	*Bushels.* 16.4	*Bushels.* 11.9
Manure Legume	8	34.4	26.5	58.5	57.4	12.4	10.2
Do	....	31.6	26.3	56.9	52.2	9.0	5.1
Do Bone meal	.... [2] 150	33.9	31.8	52.6	45.5	12.4	9.6
Legume Bone meal Potassium chloride	.... [2] 150 [2] 50	37.1	28.6	52.9	47.6	11.9	7.3
No fertilizer	....	32.4	25.5	47.9	38.8	8.5	4.5
Legume Bone meal Potassium chloride Lime	.... [2] 150 [2] 50 2,000	38.2	31.0	56.2	51.1	10.2	10.2

Fertilizer.	Application per acre.	Yield of various crops per acre.			
		Cowpea hay (1911).		Corn (1912).	
		Drained.	Undrained.	Drained.	Undrained.
Manure Rock phosphate Legume	*Tons.* [1] 8 *Pounds.* [1] 600	*Pounds.* 1,372	*Pounds.* 1,467	*Bushels.* 47.8	*Bushels.* 43.6
Manure Legume	8	1,227	1,199	44.9	41.0
Do	....	2,018	1,171	40.6	33.2
Do Bone meal	.... [2] 150	1,772	1,691	43.6	41.7
Legume Bone meal Potassium chloride	.... [2] 150 [2] 50	1,603	1,548	44.5	40.8
No fertilizer	....	1,492	1,152	42.9	40.8
Legume Bone meal Potassium chloride Lime	.... [2] 150 [2] 50 2,000	1,949	1,315	47.2	52.6

[1] Once every four years. [2] Applied before corn and again before wheat.

Not only was no comparison made between raw rock phosphate and the acidulated phosphates in this experiment, but no strict comparison can be made between the plots treated with raw rock and those receiving bone meal, as in every case the two forms of phosphoric acid were used in conjunction with different fertilizers. The plots (both drained and undrained) which were treated with raw rock, manure, and a legume, however, showed substantial increases in yield over those receiving only manure and a legume (except the drained corn plot in 1908, and the undrained oat plot in 1909).

Miller, Hutchison, and Hudelson[1] described four other experiments in which an attempt was made to study the relative fertilizer merits of raw rock phosphate and steamed bone meal in four-year rotations. The experiments were conducted on four series of plots so that each crop was grown every year. The work was carried on at the following places: Jasper County, near Carthage; on the High Hill experiment field, Montgomery County; on the Hurdland experiment field, Knox County; and on the Laclede experiment field, Linn County.

The Jasper County experiment[2] was conducted for a period of only four years and is therefore not repeated in detail but the indications were that raw rock was quite effective when used in conjunction with manure, the average yield of these plots leading all others, with the exception of the average yield of wheat on the plots treated with lime, bone meal, and potash. In this experiment also there was no comparison made between acid phosphate and the less soluble forms of phosphoric acid.

The experiment field at High Hill,[3] Montgomery County, Mo., is located "on a slight ridge which slopes considerably to the west from the center of the field, with the east one-fourth sloping slightly to the east. In neither case is the fall sufficient to cause the land to wash badly." The field had been cropped to corn and oats for about twenty-five years, being in corn about two-thirds of the time. The soil is a gray silt loam grading into a dull gray silt below, which becomes heavier with depth, and interferes somewhat with the underdrainage. The soil is low in nitrogen, but fairly well supplied with phosphoric acid and potash. The plots were one-fifth acre each, and were laid out lengthwise across the slope. The experiment which was begun in 1907 was continued to 1913 (seven years) in a four-year rotation of corn, oats, wheat, and clover, but some of the crops were apparently not weighed. During the last year of the

[1] Mo. Agr. Expt. Sta., Buls. Nos. 119, 126, 127, and 128.
[2] Mo. Agr. Expt. Sta., Bul. No. 119, pp. 3–17 (1914).
[3] Mo. Agr. Expt. Sta., Bul. No. 126, pp. 326–333 (1915).

experiment, however, three out of four of the series of plots were planted to corn in order to determine the effect of the accumulation of fertility from previous treatments. The average results of seven years' work are given in Table XLIV.

TABLE XLIV.—*Average yields of corn, oats, wheat, cowpeas, barley, and clover hay in a 7-year experiment at High Hill, Mo. (1907–1913).*

Fertilizer.	Application per acre.	Corn, 8 crops.	Oats, 5 crops.	Wheat, 3 crops.	Cow-peas, 3 crops.	Bar-ley, 1 crop.	Clover, 1 crop.
		Bushels.	*Bushels.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*
Legume		27.1	31.0	8.5	2,117	4.7	....
Do. Bone meal	 150 pounds[1]	32.7	40.6	21.5	2,057	6.5	....
Legume Bone meal Lime	 150 pounds[1] 1 ton[2]	34.3	34.8	20.7	1,943	7.5	950
Legume Bone meal Lime Potassium chloride	 150 pounds[1] 1 ton[2] 50 pounds[1]	34.0	33.9	22.2	1,595	7.5	975
No treatment		22.5	23.9	9.0	1,267	3.7	....
Manure	8 tons[3]	33.0	27.3	12.6	1,842	3.7	....
Do. Rock phosphate	.....do[3] 500 to 800 pounds[3]	34.7	30.0	17.2	2,071	4.7	....
Manure Rock phosphate Legume	8 tons[3] 500 to 800 pounds[3] 	36.4	33.9	20.5	1,775	8.2	....
Manure Rock phosphate Legume Lime	8 tons[3] 500 to 800 pounds[3] 2 tons[2]	38.7	37.6	20.6	1,717	9.4	1,275

[1] Application made every two years.
[2] Application made every six to eight years.
[3] Application made every four years.

As in the case of the other two Missouri experiments no strict comparison can be made between the plots treated with bone and those receiving raw rock phosphate, but the indications are that the reenforcement of manure with the latter material was quite effective.

The experiment field near Hurdland,[1] Knox County, Mo., "slopes slightly to the east and to the west from the middle driveway, giving only fair drainage." The soil is a dark-gray silt loam about 10 inches deep, which grades into heavier silt loam and finally into clay loam. According to the chemical analysis the soil was well supplied with potash and phosphoric acid, but low in nitrogen. The field had been in corn and oats for four years preceding the experiment, and previously had been in meadow. The field was laid out (like the three just described) in four tracts (A, B, C, and D) of eight plots each, the corresponding plots in each tract receiving the same fertilizer treatments. A four-year rotation of corn, oats, wheat, and clover (with cowpeas substituted when clover failed) was followed, each crop being grown on a different tract each year. The general plan of fertilizer treatment and the results of eight years' work (1907–1914) are given below in Table XLV.

[1] Mo. Agr. Expt. Sta., Bul. No. 127, pp. 362–370 (1915).

TABLE XLV.—*Average yields of corn, oats, wheat, clover, cowpeas, and oat hay in an 8-year experiment at Hurdland, Mo. (1907–1914).*

Fertilizer.	Application per acre.	Corn, 8 crops.	Oats, 6 crops.	Wheat, 6 crops.	Clover, 3 crops.	Cow-peas, 1 crop.	Oat Hay, 1 crop.
		Bushels.	*Bushels.*	*Bushels.*	*Pounds.*	*Pounds.*	*Pounds.*
Legume		29.3	27.9	14.4	2,500	3,850	3,850
Do. Bone meal	 150 pounds [1]	29.3	31.2	18.1	3,213	7,150	4,150
Legume Bone meal Lime	 150 pounds [1] 1 ton [2]	34.1	35.2	18.0	3,775	5,850	4,650
Legume Bone meal Lime Potassium cholride	 150 pounds [1] 1 ton [2] 50 pounds [1]	37.8	34.3	17.1	4,116	6,100	4,050
No treatment		33.1	26.9	13.7	2,741	4,200	2,200
Manure	8 tons [3]	41.6	31.6	17.7	3,341	3,525	3,225
Do. Rock phosphate	8 tons [3] 1,000 pounds [3]	40.4	32.0	17.2	3,241	5,450	3,700
Manure Rock phosphate Legume	8 tons [3] 1,000 pounds [3] 	35.2	35.7	18.5	3,300	4,150	3,500

[1] Applications made every two years.
[2] Applications made every six years.
[3] Applications made every four years.

In the Hurdland experiment the addition of phosphate rock to manure seemed to have little effect, except in the case of cowpeas and oat hay, where the yields were considerably greater than on the plots receiving manure alone. Bone meal also seemed to be more effective on these same crops, but as in the case of the other experiments the data are such that no rigid conclusion can be drawn from a comparison of the results as to the relative value of the two forms of phosphoric acid.

The fourth experiment, similar in most respects to the three just described, is being conducted near Laclede, Linn County, Mo. The last published report [1] gives the results obtained after eight years' work in a four-year rotation of corn, oats, wheat, and clover (substituting cowpeas when the latter crop failed).

The field is located on gently rolling prairie land. The soil is the typical Shelby loam, which consists of a dark-brown loam to fine sandy loam, changing at a depth of about 10 inches to a light-brown or grayish-brown loam. The subsoil below 18 inches is a light-brown stiff sandy clay. According to the analysis the phosphoric acid and nitrogen content of this soil was rather low. The field was laid out in four tracts, each tract being subdivided into eight plots, as in the case of the three experiments just described. The fertilizer applications were the same as in the Hurdland experiment.

The results of eight years' work on the Laclede field are given in Table XLVI.

[1] Mo. Agr. Expt. Sta., Bul. No. 128, pp. 388–394 (1915).

TABLE XLVI.—*Average yields of corn, oats, wheat, clover, and cowpeas in an 8-year experiment at Laclede, Mo. (1907–1914).*

Fertilizer.	Application per acre.	Corn, 6 crops.	Oats, 6 crops.	Wheat, 6 crops.	Clover, 2 crops.	Cowpeas, 4 crops.
		Bushels.	*Bushels.*	*Bushels.*	*Pounds.*	*Pounds.*
Legume		32.6	28.3	14.4	2,970	2,727
Do. Bone meal	 150 pounds[1]	39.1	35.3	16.9	4,540	3,377
Legume Bone meal Lime	 150 pounds[1] 1 ton[2]	43.3	37.3	16.2	4,650	3,604
Legume Bone meal Lime Potassium chloride	 150 pounds[1] 1 ton[2] 50 pounds[1]	46.1	40.3	19.9	4,940	3,582
No treatment		36.1	32.7	13.1	3,426	2,396
Manure	8 tons[3]	47.2	35.6	14.9	3,104	2,637
Do. Rock phosphate	8 tons[3] 500 pounds[4]	47.5	35.1	14.5	3,560	3,116
Manure Rock phosphate Legume	8 tons[3] 500 pounds[4] 	45.8	35.0	14.3	3,670	3,277

[1] Applications made every two years.
[2] Applications made every eight years.
[3] Applications made every four years.
[4] Applications made every four years, but in 1913, the rate was inceased to 1,000 pounds per acre.

The results obtained on the Laclede field are in a general way similar to those obtained at Hurdland, namely: The reenforcement of manure with phosphate rock apparently had little influence on the former's effectiveness, except in the case of the clover and cowpea crops. On the other hand, plots treated with bone meal in connection with a legume produced considerably better average yields of all crops than plots receiving the legume treatment only.

As in the case of the three previous experiments, however, no strict comparison between the bone and raw rock phosphate plots is possible, and since the yields of the various crops in the individual years are not given, the residual effect of the phosphate treatments can not be determined.

Four out of five field experiments with raw rock phosphate conducted by the Missouri Experiment Station cover a period of over five years. Two out of the four experiments reported in detail show increases resulting from the liberal use of raw rock phosphate in connection with organic matter. The other two show little or no benefit from applications of this material. No attempt was made in any of these experiments to compare the fertilizer value of raw rock and acid phosphate.

NEW JERSEY.

The first work of the New Jersey Experiment Station[1] on raw rock phosphate consisted of a series of cooperative experiments conducted by farmers in different sections of the State. Most of the experiments were conducted for one year only, and while several

[1] N. J. Agr. Expt. Sta., 6th, 7th, 8th Ann. Repts.

farmers continued their experiments for two years, the published reports show that different fields were employed the second year.

Three other series of field tests were published by the New Jersey Station in 1913,[1] but none was conducted for more than 2 years, so they do not warrant repetition.

In 1913, however, the New Jersey station carried on two pot experiments in cooperation with the basic slag committee of the Association of Official Agricultural Chemists.[2] The purpose of this investigation was to test the availability of the phosphoric acid in basic slag in comparison with other phosphates. Experiment No. 1 was conducted in pots holding 20 pounds of clean white sand practically free from any fertilizer elements. In experiment No. 2 pots were employed holding 18 pounds of gravelly loam, poor in nitrogen and organic matter, and containing about 0.07 to 0.08 per cent of P_2O_5 soluble in strong hydrochloric acid. Nitrogen, potash, iron, and sulphates were supplied to each pot. The phosphates were applied in such quantities as to furnish equal amounts of phosphoric acid, except the ground raw rock which supplied twice the quantity of phosphoric acid furnished by the other phosphates. Each treatment was run in duplicate, except the checks of which there were four. The crop grown was buckwheat which was harvested when the grain was beginning to ripen. The results of these experiments are given below in Table XLVII.

TABLE XLVII.—*Yields of buckwheat obtained in two pot experiments with pure sand and with gravelly loam treated as outlined below.*

Fertilizer.	Application per pot.	Experiment No. 1.		Experiment No. 2.	
		Weight of crop.	Increase over checks.	Weight of crop.	Increase over checks.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*
No phosphate	....	[1] 2.85	....	[1] 24.10	....
Acid phosphate	5.82	16.10	13.50	30.35	6.77
Sodium phosphate	4.97	3.30	.70	29.65	6.07
Basic slag A	5.67	14.15	11.55	31.15	7.57
Basic slag B	5.45	16.50	13.90	35.20	11.62
Basic slag C	7.79	14.95	12.35	27.80	4.22
Basic slag D	6.54	15.35	12.75	33.35	9.77
Blue rock phosphate	7.05	9.85	7.25	24.40	.82
Double superphosphate	2.24	17.75	15.15	31.70	8.12
No phosphate	....	[1] 2.35	....	[1] 23.05	....

[1] Average of two pots.

In experiment No. 1, where the crop was grown in pots containing pure sand to which the same amounts of sodium nitrate, potassium sulphate, etc., were added, the water soluble phosphates produced the

[1] N. J. Agr. Expt. Sta., 34th Ann. Rept. (1914); 35th Ann. Rept. (1915).
[2] N. J. Agr. Expt. Sta., 34th Ann. Rept., 481–484 (1914).

largest yields, closely followed, however, (and in one case equaled) by the basic-slag pots. The raw rock phosphate pots produced an appreciable increase in yield over the no-phosphate pots, but far less than any of the other treated pots except those receiving sodium phosphate. This latter compound, it is said, seemed to have a toxic effect.

In experiment No. 2, where a soil was employed, the raw-rock pots gave little or no increase over the checks, while those treated with basic slag produced in most instances greater yields than the acid phosphate pots.

The data obtained in these pot experiments, however, are of such limited value (owing to their short duration, and also to the fact that only a single crop was tested) that the writers have hesitated to present them, but as far as they go they indicate that liberal applications of phosphoric acid in the form of acid phosphate and basic slag were superior to twice the quantity in the form of raw rock phosphate.

NEW YORK.

The first three experiments[1] conducted by the New York Experiment Station with raw rock phosphate as a fertilizer were of such short duration and the data presented are so limited that they are not considered in detail in this bulletin.

In some pot or greenhouse experiments conducted by the Geneva station from 1896 to 1900 sufficient data are given to warrant a repetition of the figures and a discussion of some of the details.

The soils in which the plants were grown in the several experiments were as follows:

In 1896–97 a natural sandy pine land soil, supposedly poor, was used (110 pounds per box). In 1898–99 quartz sand containing from 99.5 to 99.7 per cent SiO_2 was employed (46 pounds per box with 12 pounds of coarse material for drainage). In 1899–1900 for some crops the same sand which had been used during the previous year after removing roots and organic matter and for some crops an equal quantity (46 pounds) of fresh sand.

Adequate quantities of readily available nitrogen and potash carriers were added in each case and the same amount of phosphoric acid was added to each can or box in the forms given in the table. The effect of these phosphates on the yield of several orders of plants was studied by running each treatment in duplicate.

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[1] N. Y. Agr. Expt. Sta., 7th Ann. Rept., pp. 356–363 (1889); 8th Ann. Rept., pp. 256–258 (1890); Cornell Buls. Nos. 143 (1898); 166 (1899); 182 (1900); 201 (1902).

TABLE XLVIII.—*Yields of certain crops obtained in pots containing 110 pounds of poor sandy soil treated with available nitrogen and potash, etc., and various phosphates.*

Fertilizer.	Application of P_2O_5 per pot.	Yield (1896–97).					
		Oats.	Rye.	Beans.	Vetch.	Cabbage.	Rape.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Acid phosphate	4	93.5	226.8	22.4	111.2	57.5	61.4
Florida rock (floats)	4	85.7	205.5	13.8	85.7	53.0	55.2
Thomas slag	4	115.1	212.0	14.8	98.8	54.8	60.7
Redonda phosphate	4	93.0	215.0	16.9	87.6	53.2	59.5
No phosphate		90.7	194.0	13.3	75.3	53.0	45.8
No fertilizer (of any kind)		7.3	39.5	11.1	75.6	13.0	11.4

TABLE XLIX.—*Yields of certain crops obtained in boxes containing 46 pounds of pure sand (99.6 per cent SiO_2), treated with available nitrogen and potash, etc., and with various phosphates.*

Form of phosphate.	Application per box.	Yield of crops (1898–99).							
		Barley.	Millet.	Oats.	Clover.	Vetch.	Tomatoes.	Cabbage.	Rape.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Acid phosphate	3	189.6	29.2	210.2	93.8	88.5	58.7	82.2	91.4
Florida rock (floats)	3	9.3	1.1	9.1	2.6	31.8	1.8	64.5	72.3
Thomas slag	3	181.4	8.8	198.9	74.0	67.5	48.4	80.0	98.4
Redonda phosphate	3	150.1	14.4	170.2	37.1	61.9	57.2	65.4	74.9
No phosphate		7.9	1.2	6.8	2.4	2.7		.5	.8
No fertilizer (of any kind)		10.9	1.1	10.0	4.5	2.7		3.6	3.4

TABLE L.—*Yield of certain crops obtained in boxes containing 46 pounds pure sand (99.6 per cent SiO_2), treated with available potash and nitrogen, etc., and with various phosphates.*

Form of phosphate.	Application per box.	Yield of crops (1899–1900).					
		Barley.	Peas.	Vetch.	Tomatoes.	Cabbage.[1]	Rape.[1]
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Acid phosphate	1.5	34.2	19.8	9.6	11.5	38.3	29.3
Florida rock (floats)	1.5	8.8	12.5	4.8		46.0	28.1
Thomas slag	1.5	21.1	15.9	8.1	8.4	45.8	10.9
Redonda phosphate	1.5	18.6	13.8	8.3	7.6	20.0	17.1
No phosphate		6.8	7.7	2.6			
No fertilizer (of any kind)		4.9	3.7	2.0			

[1] Cabbage and rape were grown on the sand used the previous year to which 4 grams of P_2O_5 were added in the various forms given above.

A study of Tables XLVIII, XLIX, and L will show that the cruciferous plants (cabbage and rape) seemed to utilize the phosphoric acid of raw rock phosphate almost as well as they did the more soluble forms, but that nearly all the other plants gave greater yields where they were treated with acid phosphate. In Table LXVIII, where a sandy soil was used, the difference between the soluble and insoluble phosphate pots was not so marked, owing in part no doubt to the fact that the soil originally contained phosphates. In the

other two experiments, however, the sand used contained no phosphate, except that added and it is rather surprising that such additions of raw phosphate as were made, applications supplying from 0.008 to 0.014 per cent of phosphoric acid, which is less than that contained in a soil abnormally low in this element, should have proved so effective, particularly in the absence of organic matter. In order to test the influence of fine grinding on the availability of raw rock phosphate and bones two pot experiments were conducted under the direction of W. H. Jordon[1] of the Geneva station. In one of these experiments (1899–1900) 58 pounds of pure quartz sand per pot were used to which no organic matter had been added, and in the other (1903–4) 43 pounds of sand per pot were employed to which about 3 per cent of dried ground sphagnum moss was added. In both experiments all the pots except the blanks were supplied with the necessary fertilizer elements, the phosphoric acid, however, being applied in the forms of acid phosphate, bone, and ground raw rock of various degrees of fineness.

In the first experiment three successive crops of rape were grown without renewing the phosphate treatments for the second and third crops, but the barley was grown in a separate set of pots. In the second experiment the crops grown were peas, barley, and rape, but each in separate sets of pots. The plants in every instance were allowed to attain the fullest development possible under the conditions. They were then harvested and weighed. The results obtained are given in part in Table LI which is compiled from two tables taken from Bulletin No. 358, of the Geneva station.

TABLE LI.—*Box experiment to test the effect of raw rock phosphate of various degrees of fineness on different crops; boxes contained 46 pounds each of pure quartz sand supplied with all fertilizer elements.*

Treatment.	Application of P_2O_5 per box.[2]	1899–1900				1903–4		
		Rape, first crop.	Rape, second crop.	Rape, third crop.	Barley.	Peas.	Barley.	Rape.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Blanks						8.4	12.2	
Acid phosphate	3	72.3	49.3	26.2	66.4	69.9	166.7	48.0
Florida rock:								
60-mesh	3	47.5	30.9	25.0	7.6	64.1	140.0	54.5
80-mesh	3	36.5	30.1	27.6	9.0	63.1	165.7	58.2
100-mesh	3	37.6	28.5	29.3	6.8	62.8	176.3	56.3
Bolting cloth	3	46.3	28.4	29.4	7.8	60.3	164.4	58.7
Fine	3	45.2	34.0	31.3	7.3	67.5	172.9	58.8
Floats	3	52.8	35.6	32.4	11.1	68.0	162.7	57.7
Bone meal:								
60-mesh	3	54.8	36.9	32.7	9.8	59.8	160.0	46.5
80-mesh	3	53.0	35.9	33.0	7.3	60.4	168.7	46.8
100-mesh	3	54.5	40.1	32.7	6.9	62.7	175.3	40.7
Bolting cloth	3	60.9	35.1	36.0	6.9	61.6	164.6	44.8
Finest	3	49.2	39.4	26.7	9.5	59.6	177.0	48.6

[1] N. Y. Agr. Expt. Sta. (Geneva), Bul. No. 358 (1913).
[2] In the experiments conducted in 1903–4 only 1.5 grams of P_2O_5 per pot were used, but organic matter was added in the form of sphagnum moss.

It is evident from the figures given in Table LI that the more finely raw rock phosphate is ground the more effective it becomes. The floats in almost every instance produced appreciably greater yields than the coarser phosphatic material. The same is true, though to a less extent, of bone meal.

In the first experiment (1899–1900) where no organic matter was applied, the pots treated with acid phosphate showed greater yields than those treated with the less soluble phosphates, but in the second experiment where organic matter was added the very finely ground raw rock and floats gave as good and better yields than the acid phosphate, although it was supplied in quantities far less than phosphates occur in most soils.

One other pot experiment to test the fertilizer value of several relatively insoluble phosphates on barley was conducted by the Geneva[1] station in 1912.

The same artificial soil employed in the previous experiments was used in this test, but the quantity of phosphoric acid added to each pot in the various forms was from two to four times as great. Adequate amounts of potash and nitrogen were added to each pot, but no organic matter was employed. Each treatment was run in duplicate.

The average results of this experiment are given in Table LII.

TABLE LII.—*Yields of barley obtained in a pot experiment (58.9 pounds of soil) with various phosphatic fertilizers; potash and nitrogen supplied to all pots.*

Form of phosphates.	Amount of P_2O_5 added per pot.	Yield of barley per pot.
	Grams.	*Grams.*
Monocalcium phosphate	5.82	71.0
Iron ore waste	5.82	44.2
Basic slag	5.82	68.7
Ground Tennessee rock	5.82	55.7
Bone	5.82	74.7
Blanks	....	38.2

The monocalcium phosphate, bone, and basic-slag treatments all gave yields of barley greater than the ground Tennessee rock, but apparently this crop was able to utilize to a certain extent the phosphoric acid of this latter material.

In view of the fact that barley in previous experiments has not responded readily to the less soluble forms of phosphoric acid when they were present in small quantities, the results of this experiment are not surprising, for while greater amounts of phosphoric acid

[1] N. Y. Agr. Expt. Sta. (Geneva). Fertilizer Value of An Iron Ore Waste. Bul. No. 358, pp. 252–253 (1913).

were added than in the previous experiments with the artificial soil, the total quantity present in each pot was still considerably below that present in a soil of low phosphate content.

While only one field experiment (of two years' duration) with raw rock phosphate has been reported by the New York stations, the six pot experiments warranting consideration in detail indicate that this material increases the yield of a number of crops even when applied in very small quantities. The data also seem to show that the presence of organic matter renders the raw phosphate more effective. A comparison of the relative merits of the different phosphates used in these experiments, however, is hardly admissible.

NORTH CAROLINA.

The work with raw rock phosphate reported by this State consists of three field experiments[1] conducted for periods of one to three years. Owing to the short duration of these experiments and also to the fact that the data presented in two of them are very limited, one is hardly justified in considering the results even indicative of the relative merits of the phosphates used.

OHIO.

Probably the most valuable experiment with raw rock phosphate yet reported is one undertaken by the Ohio station in 1897.[2] Not only has this experiment been conducted over a considerable period of time (18 years), but the raw rock phosphate has been applied in a manner generally thought to render it most effective under soil conditions. Moreover, a direct comparison is made between this form and the more soluble form of phosphoric acid in superphosphate.

The field selected for this experiment was rather below the average in fertility, but no data are available showing the relative natural productivity of the treated plots. The yields of most of the check plots, however, with the exception of No. 1, section A, No. 7, section B, and No. 1, section C, have agreed fairly well throughout the experiment, indicating that the field is comparatively uniform. The soil is a sandy clay of glacial drift origin. In 1892 it grew a crop of oats and in 1893 it was plotted, drained, and sown to wheat. Clover and timothy were grown in 1895 and 1896.

Up to the time of the experiment herein described, no manure whatever had been applied to the field since it came into the possession of the State.

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[1] N. C. State Board of Agr., Bul. No. 128 (1907) ; N. C. Dept. Agr., Bul. No. 151, pp. 31–34 (1911) ; N. C. Agr. Expt. Sta., Bul. No. 227 (1914).

[2] Ohio Agr. Expt. Sta., Buls. Nos. 110, 134, 183, 184, 246, 305 ; Circulars Nos. 54, 83, 92, 104, 114, 120, 131, 144.

In 1897 the field was divided into three tracts containing 20 plots each, and a three-crop rotation of corn, wheat, and clover begun, so that each crop was grown every year and each tract received every third year the fertilizer treatments outlined below.

A quantity of manure from the stable, where it had collected under the feet of animals kept continually in their stalls, was taken and divided into five equal parts, four of which were treated with various reenforcing materials at the rate of 40 pounds to the ton of manure. The fifth portion was left untreated. Equal or equivalent amounts of manure from the open barnyard were similarly treated with the same materials. After standing for some time the manure thus treated was spread upon clover sod at the rate of 8 tons to the acre, and plowed under for corn which was followed by wheat and clover. During the first three seasons soy beans were grown and plowed under, since clover was a failure. The arrangement of the plots is shown in the following diagram taken from the Ohio station reports; and the average yields per acre for 18 crops[1] and the increases in yield due to the various applications are given in Tables LIII and LIV.

Arrangement of plots and plan of fertilizing in experiments with manure; plots one-sixteenth acre each.

11. Nothing.		Nothing.	1.
12. Yard manure, gypsum.		Yard manure, floats.	2.
13. Stall manure, gypsum.		Stall manure, floats.	3.
14. Nothing.		Nothing.	4.
15. Yard manure, untreated.	Section	Yard manure, acid phosphate.	5.
16. Stall manure, untreated.	A.	Stall manure, acid phosphate.	6.
17. Nothing.		Nothing.	7.
18. Chemical fertilizer.		Yard manure, kainit.	8.
19. Chemical fertilizer.		Stall manure, kainit.	9.
20. Nothing.		Nothing.	10.
11. Nothing.		Nothing.	1.
12. Yard manure, gypsum.		Yard manure, floats.	2.
13. Stall manure, gypsum.		Stall manure, floats.	3.
14. Nothing.		Nothing.	4.
15. Yard manure, untreated.	Section	Yard manure, acid phosphate.	5.
16. Stall manure, untreated.	B.	Stall manure, acid phosphate.	6.
17. Nothing.		Nothing.	7.
18. Chemical fertilizer.		Yard manure, kainit.	8.
19. Chemical fertilizer.		Stall manure, kainit.	9.
20. Nothing.		Nothing.	10.
11. Nothing.		Nothing.	1.
12. Yard manure, gypsum.		Yard manure, floats.	2.
13. Stall manure, gypsum.		Stall manure, floats.	3.
14. Nothing.		Nothing.	4.
15. Yard manure, untreated.	Section	Yard manure, acid phosphate.	5.
16. Stall manure, untreated.	C.	Stall manure, acid phosphate.	6.
17. Nothing.		Nothing.	7.
18. Chemical fertilizer.		Yard manure, kainit.	8.
19. Chemical fertilizer.		Stall manure, kainit.	9.
20. Nothing.		Nothing.	10.

[1] This applies to all plots, except the commercial fertilizer plots the results of which are the averages of 16 years.

TABLE LIII.—*Yields per acre of corn, wheat, and hay—average for the 18-year period, 1897–1915.*

Plot number.	Treatment.	Corn.		Wheat.		Hay.
		Grain.	Stover.	Grain.	Straw.	
		Bushels.	*Pounds.*	*Bushels.*	*Pounds.*	*Pounds.*
1	None	40.62	2,365	13.28	1,543	3,020
2	Yard manure and raw phosphate	63.40	3,464	24.94	2,674	4,357
3	Stall manure and raw phosphate	66.75	3,677	26.46	2,869	4,765
4	None	32.38	2,050	11.75	1,370	2,299
5	Yard manure and acid phosphate	63.69	3,372	26.57	2,907	4,260
6	Stall manure and acid phosphate	67.04	3,578	27.06	3,031	4,851
7	None	31.16	1,982	10.90	1,319	2,314
8	Yard manure and kainit	56.67	3,232	21.52	2,423	3,547
9	Stall manure and kainit	61.54	3,475	23.13	2,691	4,238
10	None	34.14	2,049	11.14	1,364	2,488
11	.....do	38.97	2,375	14.40	1,732	3,251
12	Yard manure and gypsum	60.62	3,400	24.39	2,712	3,885
13	Stall manure and gypsum	61.48	3,498	24.31	2,695	3,909
14	None	31.77	2,037	11.29	1,334	2,354
15	Yard manure, untreated	52.85	2,921	20.72	2,296	3,337
16	Stall manure, untreated	59.37	3,271	22.03	2,494	4,000
17	None	37.94	2,331	11.59	1,409	2,694
18	Chemical fertilizer	47.78	2,690	16.16	1,841	3,163
19	.....do	45.20	2,494	15.42	1,885	3,255
20	None	33.88	2,028	10.72	1,382	2,679
	Average from manure and raw phosphate	65.07	3,570	25.70	2,771	4,561
	Average from manure and acid phosphate	65.36	3,475	26.81	2,969	4,555
	Average from manure untreated	56.11	3,096	21.37	2,395	3,668
	Average unmanured yields	34.77	2,153	11.76	1,395	2,536

TABLE LIV.—*Barnyard manure on crops grown in three-year rotation. Average annual increase per acre for entire period of experiment figured first according to Thorne, by comparing treated plots with the two nearest check plots, and second by comparing treated plots with average of all check plots.*

Plot number.	Treatment.	Average annual increase according to Thorne.				
		Corn, 18 crops.		Wheat, 18 crops.		Clover hay, 15 crops.
		Grain.	Stover.	Grain.	Straw.	
		Bushels.	*Pounds.*	*Bushels.*	*Pounds.*	*Pounds.*
2	Yard manure and floats	25.53	1,204	12.17	1,189	1,578
3	Stall manure and floats	30.95	1,522	14.20	1,492	2,225
5	Yard manure and acid phosphate	31.72	1,344	15.09	1,554	1,956
6	Stall manure and acid phosphate	35.48	1,572	15.68	1,693	2,542
8	Yard manure and kainit	24.11	1,237	10.54	1,089	1,176
9	Stall manure and kainit	28.40	1,449	12.07	1,343	1,807
12	Yard manure and gypsum	23.83	1,171	11.02	1,113	931
13	Stall manure and gypsum	27.31	1,348	11.97	1,229	1,255
15	Yard manure, untreated	19.03	815	9.33	939	870
16	Stall manure, untreated	23.48	1,015	10.46	1,110	1,419
18	Chemical fertilizer[1]	10.74	475	4.22	394	482
19	.....do[2]	10.48	400	4.26	472	635

[1] Acid phosphate, 80 pounds; muriate of potash, 80 pounds; nitrate of soda, 160 pounds.
[2] Acid phosphate, 80 pounds; muriate of potash, 10 pounds; tankage (7–30), 100 pounds

TABLE LIV.—*Barnyard manure on crops grown in three-year rotation, etc.*—Con.

Plot number.	Treatment.	Average annual increase obtained by comparison with average of all check plots.				
		Corn, 18 crops.		Wheat, 18 crops.		Clover hay, 15 crops.
		Grain.	Stover.	Grain.	Straw.	
		Bushels.	*Pounds.*	*Bushels.*	*Pounds.*	*Pounds.*
2	Yard manure and floats	27.54	1,312	13.06	1,242	1,718
3	Stall manure and floats	30.88	1,525	14.58	1,437	2,138
5	Yard manure and acid phosphate	27.83	1,220	14.69	1,475	1,621
6	Stall manure and acid phosphate	31.18	1,426	15.18	1,599	2,214
8	Yard manure and kainit	20.81	1,080	9.64	991	910
9	Stall manure and kainit	25.68	1,323	11.25	1,259	1,601
12	Yard manure and gypsum	24.76	1,248	12.51	1,280	1,278
13	Stall manure and gypsum	25.52	1,346	12.43	1,263	1,272
15	Yard manure, untreated	16.99	769	6.40	864	700
16	Stall manure, untreated	23.51	1,119	10.78	1,062	1,363
18	Chemical fertilizer[1]	12.24	548	3.88	392	585
19	....do[2]	10.58	359	3.73	471	722

[1] Acid phosphate, 80 pounds; muriate of potash, 80 pounds; nitrate of soda, 160 pounds.
[2] Acid phosphate, 80 pounds; muriate of potash, 10 pounds; tankage (7–30), 100 pounds.

A study of Table LIII will show that applications of stall manure produced greater yields than yard manure, and that the mixing of floats with the stall manure rendered them considerably more effective than where they were mixed with yard manure.

Phosphates proved more desirable as reenforcers of manure than either kainit or gypsum. Where the two forms, raw rock and acid phosphate, were thus used at the rate of 320 pounds per acre every three years, the plots treated with the latter gave slightly greater yields. Moreover, in spite of the fact that a greater quantity of phosphoric acid had actually been added to the plots in the form of raw rock phosphate, and the conditions were favorable for rendering this accumulated phosphoric acid available, the acid phosphate treatments appeared to be slightly more effective even after 17 years.

On the other hand, Thorne in comparing the various fertilizer treatments with the check plots assumes that any change in fertility of the soil of the various plots in the experiment field is gradual and, therefore, the treated plot under consideration should be compared with the nearest check plots rather than with the average of all the checks.

Hopkins[1] takes issue with Thorne on this point, saying "that the change in the direction of such a curve is just as likely to occur on any other plot as on the plots that happen to be numbered 1, 3, 4, 7, etc." The latter writer also points out that several of the check plots in this experiment are apparently abnormal, and Thorne's system of comparison is unfavorable if not unfair to the raw rock plots.

[1] Soil Fertility and Permanent Agriculture, p. 250.

In Table LIV the average annual increase per acre for each treatment is figured both by the Ohio system and also by comparing the treated plots with the average of all the check plots. These two systems of comparison lead to very different conclusions. By the Ohio method acid phosphate appears to much greater advantage than raw rock, even though the latter is considerably less costly. By the second method of comparison the applications of raw rock phosphate show increases in yield practically as good and in some cases better than those obtained from equal applications of acid phosphate.

Another point worthy of serious consideration in this experiment is that the applications of raw rock were not very liberal for such a relatively insoluble material, the effectiveness of which depends largely on its thorough distribution in the soil. Such distribution must be brought about principally by heavy applications. According to analysis, the soil on which this experiment was conducted was relatively low in phosphoric acid (0.08 per cent P_2O_5) yet even had none of the phosphate rock added during the 17 years of the experiment been removed by crops or lost in other ways, the total quantity of phosphoric acid present in the upper 9 inches of the soil would only have been increased to 0.1 per cent. The crops grown were such as would remove an amount of phosphoric acid equal approximately to one-half of that added in the form of raw rock so at the expiration of 17 years the soil should have contained about 0.01 per cent more phosphate than at the beginning of the experiment, an amount which in spite of thorough tillage and frequent cultivation was probably not uniformly distributed in the soil. An experiment similar to the one just described, except using heavier applications of phosphate rock would be interesting, and yield valuable data on this subject.

Another experiment with raw rock phosphate in which a three year rotation of corn, oats, and clover was followed, was begun at Wooster in 1905.[1] The following description of the field employed, and the history of the experiment which is known as the Lime and Floats Test, is taken directly from Circular No. 144 of the Ohio Station:

The land had been under the regular rotative cropping of the farm since its occupation by the Station, and for a considerable period before, and was in good condition—12 tons of manure per acre had been plowed under for corn in 1904. Three sections of 26 plots each are included in the test, the plots containing one-twentieth acre each.

For the crops of 1905, section A (north end) was manured at the rate of 6 tons per acre only (because of the recent application above mentioned), limed, fertilized, and planted to corn. Section B was sown to soy beans instead of clover, the beans to be followed by rye in the fall and corn in 1906. Section C

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[1] Ohio Agr. Expt. Sta., Circular No. 144, pp. 92–93 (1914).

(south end) was limed and fertilized without manure, and sown to oats and clover. Thenceforth the manure, lime, and fertilizers have all been applied to the corn crops, the manure being plowed under and the lime and fertilizers applied to the surface. The oats and clover receive no treatment. The clover seeding failed in 1906, 1908, and 1909, and soy beans were grown instead and harvested as hay.

The plan of treatment, average yields per acre, for nine years, and the increase per acre from the various treatments figured according to the Ohio method and also by comparing each treatment with the average of all the untreated plots are given in Table LV.

The results obtained in 1914 and 1915 have been reported by Thorne in Bulletin No. 305 of the Ohio station, but no yields are given except those of the plots receiving acid phosphate and raw rock. These last two years' results therefore are not included in the averages given in Table LV.

TABLE LV.—*Average yields and increase per acre of crops grown in 3-year rotation under treatment with manure, lime, and floats.*

[Plots one-twentieth acre each.]

Plot number.	Treatment (lime, manure, etc., per acre applied to corn only).	Average yield per acre, 1905–1913, inclusive.					Average increase in yield per acre.									
		Corn, 9 years.		Oats, 9 years.		Clover-cowpea hay, 8 years.	According to Thorne.					Obtained by comparison with average of all check plots.				
							Corn.		Oats.		Hay, 8 years.	Corn.		Oats.		Hay, 8 years.
		Grain.	Stover.	Grain.	Straw.		Grain.	Stover.	Grain.	Straw.		Grain.	Stover.	Grain.	Straw.	
		Bush.	*Lbs.*	*Bush.*	*Lbs.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Lbs.*
1	None	52.57	2,804	43.16	2,267	4,201										
2	Caustic lime, 500 pounds; manure, 8 tons	70.42	3,500	50.98	2,502	5,313	17.57	670	6.66	294	1,030	18.92	741	6.04	541	1,239
3	Caustic lime, 1,000 pounds; manure, 8 tons	72.62	3,584	51.20	2,477	5,470	19.48	728	5.72	329	1,165	21.12	825	6.26	516	1,396
4	None	53.42	2,882	46.64	2,089	4,447										
5	Caustic lime, 2,000 pounds; manure, 8 tons	75.95	3,833	52.70	2,536	5,933	21.80	930	5.96	441	1,470	24.45	1,074	7.76	575	1,859
6	Ground limestone, 1,780 pounds; manure, 8 tons	75.14	3,649	53.08	2,526	5,634	20.26	724	6.24	426	1,156	23.64	890	8.14	565	1,560
7	None	55.61	2,974	46.93	2,104	4,492										
8	Air slaked lime, 1,780 pounds; manure, 8 tons	74.74	3,809	53.75	2,628	5,766	19.84	902	7.43	551	1,393	23.24	1,050	8.81	667	1,692
9	Hydrated lime, 1,320 pounds; manure, 8 tons	71.70	3,722	53.53	2,617	5,520	17.52	856	7.84	567	1,265	20.20	963	8.59	656	1,446
10	None	53.46	2,827	45.08	2,022	4,135										
11	Gypsum, 1,000 pounds; manure, 8 tons	67.28	3,387	51.86	2,268	4,605	15.10	611	6.87	295	566	15.78	628	6.92	307	531
12	Floats, 1,000 pounds; manure, 8 tons	67.43	3,387	53.42	2,383	4,768	16.54	661	8.54	459	827	15.93	628	8.48	422	694
13	None	49.60	2,676	44.78	1,876	3,844										
14	Caustic lime, 1,000 pounds	57.33	3,149	47.53	2,079	4,580	7.74	461	2.63	218	771	5.83	390	2.59	118	506
15	Ground limestone, 1,780 pounds	54.84	2,820	45.35	1,876	4,362	5.26	121	.32	28	588	3.34	61	.41	00	288
16	None	49.58	2,711	45.14	1,833	3,738										
17	Caustic lime, 1,000 pounds; acid phosphate, 320 pounds; muriate potash, 40 pounds	70.45	3,558	50.55	2,061	5,084	20.13	829	5.40	202	1,264	18.95	799	5.61	100	1,010
18	Caustic lime, 1,000 pounds; floats, 320 pounds; muriate potash, 40 pounds	66.43	3,438	48.35	1,972	4,991	15.36	691	3.18	87	1,091	14.93	679	3.41	11	917
19	None	51.81	2,764	45.19	1,911	3,981										
20	Acid phosphate, 320 pounds	60.18	3,056	46.16	1,912	4,277	8.55	315	1.19	37	271	8.68	297	1.22	00	202
21	Acid phosphate, 320 pounds; muriate of potash, 40 pounds	66.22	3,327	47.88	2,014	4,443	14.78	611	3.14	176	413	14.72	568	2.94	53	369
22	None	51.27	2,691	44.52	1,802	4,055										
23	Floats, 320 pounds	53.58	2,742	45.17	1,842	4,060	4.06	104	1.16	57	104	2.08	00	.23	00	00
24	Floats, 320 pounds; muriate of potash, 40 pounds	56.63	3,016	44.80	1,808	3,912	8.87	431	1.31	42	54	5.13	257	00	00	00

25	None	46.01	2,531	42.98	1,749	3,759										
26	Manure, 8 tons since 1909 [1]	55.97	3,049	46.56	1,951	4,475	17.34	816	3.58	202	715	4.47	290	1.62	00	401
	Average unfertilized yield	51.50	2,759	44.94	1,961	4,074										

[1] Previously, floats, 320 pounds; muriate potash, 40 pounds; dried blood, 100 pounds.

NOTE.—The lime or gypsum or floats and manure are not mixed together. The manure is plowed under and the lime or other materials applied to the surface.

An inspection of Table LV will show that here again very different conclusions may be drawn from the experimental data, depending on the method used in comparing the checks with the various fertilized plots.

According to the Ohio method of comparison raw rock phosphate when applied alone at the rate of 320 pounds per acre gave some slight increases in yield, though not as great as the same quantity of acid phosphate. By the second method of comparison, however, practically no increase was obtained from such small applications of raw rock.

Again, by the Ohio method of calculation, manured plots on which raw rock phosphate was applied at the rate of 1,000 pounds per acre as a top dressing gave an average increase in yield less than that obtained from plots receiving manure alone. According to the second method of comparison, however, the plots receiving such heavy applications of phosphate rock produced considerably greater yields than those receiving manure alone. There were no plots in this experiment on which acid phosphate and manure were used in conjunction.

Another experiment with raw rock phosphate, using a rotation of beets, oats, and clover, was begun by the Paulding County Experiment Station in 1911,[1] but since the data so far published on this experiment cover only three years or one complete rotation it is too early to draw any conclusions therefrom.

In what are known as the "Strongville experiments"[2] the Ohio station has made a comparison of the relative effect of lime and floats in a five-year rotation of corn, oats, wheat, clover, and timothy.

The field used in this experiment is nearly level east and west, but slopes gently to the north. It was divided into four sections (A, B, C, and D) containing 40 plots of one-tenth acre each. The soil of the field is a heavy white clay naturally low in phosphoric acid, and had been employed in a fertilizer experiment under the same system of rotation for 12 years. After the introduction of the lime and floats the applications of the other fertilizer materials were continued as before, but each plot was divided into two parts, on one of which floats were applied and on the other ground limestone. The dressings have been 2 tons of limestone per acre on the south half of each entire section, and 1 ton of floats per acre on the north half, the applications being made on the corn crop only. The average yields of the checks and the variously treated plots in each section from 1905 to 1912, inclusive, are given in Table LVI.

[1] Ohio Agr. Expt. Sta., Buls. Nos. 258, 273, 286.
[2] Ohio Agr. Expt. Sta., Bul. No. 260.

TABLE LVI.—*Average yields of crops in five-year rotation— Yields by sections computed according to Ohio system.*[1]

Section.	Year.	Crop.	Plots, treatment, and yield per acre.									
			Unfertilized.		Plots Nos. 18, 20, 39, yard manure.		Plots Nos. 3, 5, 9, nitrogen or potassium, no phosphorus.		Plots Nos. 17 to 33, complete fertilizer, low nitrogen.		Plots Nos. 11 to 36, complete fertilizer, high nitrogen.	
			Lime.	Floats.	Lime.	Floats.	Lime.	Floats.	Lime.	Floats.	Lime.	Floats.
Section D	1905	Corn, bushels	38.25	35.15	52.86	51.65	38.23	34.64	54.67	52.83	51.86	49.01
	1906	Oats, bushels	30.21	39.50	30.28	43.89	31.95	39.76	43.01	46.98	41.86	48.68
	1907	Wheat, bushels	12.09	14.09	31.43	25.70	11.80	12.61	25.18	22.11	29.37	25.62
	1908	Clover, pounds	2,441	5,117	3,946	5,226	3,038	5,503	3,725	5,325	3,961	5,576
	1909	Timothy, pounds	1,853	4,604	2,155	4,305	2,091	3,758	2,041	4,642	2,383	4,548
	1910	Corn, bushels	9.70	17.46	16.15	19.14	10.27	18.79	12.60	18.57	12.18	19.67
	1911	Oats, bushels	40.36	49.23	50.61	54.40	42.20	54.24	52.69	58.53	54.08	59.90
	1912	Do	31.84	42.56	43.36	49.29	31.51	44.80	43.48	50.67	41.47	51.72
Section C	1906	Wheat, bushels	3.23	3.52	14.09	14.73	4.32	7.11	18.99	16.99	19.46	18.44
	1907	Clover, pounds	3,038	3,850	4,880	4,897	3,418	4,408	4,240	4,101	4,400	4,173
	1908	Timothy, pounds	3,084	2,706	4,139	3,908	3,056	3,109	3,938	3,382	4,171	3,402
	1909	Corn, bushels	30.78	33.18	50.34	49.75	29.82	39.39	54.49	50.15	52.25	45.93
	1910	Oats, bushels	31.62	37.35	36.38	42.99	34.56	34.03	34.36	38.42	34.11	38.18
	1911	Wheat, bushels	6.38	7.31	14.84	14.60	5.39	7.37	16.33	12.20	14.20	11.18
	1912	Clover, pounds	2,531	2,512	5,066	4,894	2,365	2,756	4,293	2,808	3,879	2,831
Section A	1907	Corn, bushels	17.56	23.23	23.49	26.42	20.78	26.27	27.16	22.54	25.42	29.01
	1908	Oats, bushels	27.90	36.14	40.12	54.36	35.11	52.29	48.85	60.01	44.90	55.87
	1909	Wheat, bushels	11.29	17.26	17.73	20.30	11.93	17.85	20.61	20.02	20.42	20.07
	1910	Clover, pounds	1,938	4,743	3,450	5,347	1,955	4,691	3,536	4,760	3,467	5,309
	1911	Timothy, pounds	2,301	4,249	2,882	4,149	2,125	3,287	3,069	4,482	2,871	4,436
	1912	Corn, bushels	35.84	43.40	47.95	43.08	45.10	52.83	57.35	47.55	55.65	56.41
Section B	1908	Do	17.37	18.78	24.99	23.12	15.48	20.26	24.35	29.06	27.04	27.45
	1909	Oats, bushels	38.56	39.51	43.68	43.30	41.25	41.10	53.00	58.16	52.23	52.91
	1910	Wheat, bushels	8.91	8.13	13.56	13.12	10.65	7.22	17.86	17.18	18.72	17.09
	1911	Clover, pounds	1,966	2,029	2,383	2,902	2,157	2,247	1,666	2,877	2,442	3,197

[1] Since the compilation of the above data the Ohio station has published (in Bul. No. 305) the results of further work on this same field, but the yields obtained are not given for all the plots in the experiment field. These later results, therefore, could not be incorporated in the above table.

Table LVI shows that on plots receiving no other fertilizer and also on those upon which nitrogen and potash but no soluble phosphate was used, the portion treated with "floats" gave consistently greater yields than that portion treated with ground limestone. The effect of the floats also appears to be cumulative. In regard to the plots receiving stable manure, little difference is noted between the portion treated with "floats" and that receiving applications of limestone. The floats, however, were applied after the manure had been plowed under. While no direct comparison can be made between acid phosphate and ground raw rock in this experiment it will be seen that where the soluble phosphate was employed (in complete fertilizers) in addition to the floats the yields were considerably greater than where the floats were used in conjunction with potash and nitrogen carriers only.

In Table LVII the average yields of each of the five crops of the rotation throughout the entire period of the experiment are given. These averages include six crops each of corn, oats, wheat, and clover and three crops of timothy grown in four years and averaged as four crops.

TABLE LVII.—*Average yields of crops, on plots treated with lime and floats, five-year rotation, Strongville.*

Crop.	Plots and treatment and average yield per acre.									
	Unfertilized.		Plots Nos. 18, 20, 30, yard manure.		Plots Nos. 3, 5, 9, nitrogen or potassium; no phosphorus.		Plots Nos. 17 to 33, complete fertilizer, low nitrogen.		Plots Nos. 11 to 36, complete fertilizer, high nitrogen.	
	Lime.	Floats.	Lime.	Floats.	Lime.	Floats.	Lime.	Floats.	Lime.	Floats.
Corn..........bushels..	24.92	28.53	35.96	35.53	26.61	32.03	38.44	36.78	37.40	37.81
Oats..........bushels..	33.41	40.71	40.74	48.04	36.10	44.37	45.90	52.13	44.27	51.21
Wheat..........bushels..	8.38	10.06	18.33	17.69	8.82	10.43	19.79	17.70	20.43	18.48
Clover..........pounds..	2,383	3,650	3,945	4,653	2,587	3,921	3,504	3,974	3,630	4,217
Timothy..........pounds..	1,809	2,890	2,294	3,090	1,818	2,539	2,262	3,126	2,356	3,096

This table shows in a more condensed form what is shown in detail in Table LVI namely, that floats when applied liberally are effective on a soil of low phosphate content and that probably their chief function is the furnishing of phosphoric acid.

In this particular experiment the raw rock phosphate apparently became increasingly available after the soil had been plowed and cultivated for a number of years, and the finely divided rock thus more uniformly and thoroughly distributed.

The writers feel that the work of the Ohio Experiment Station shows pretty conclusively that even medium applications of ground raw rock phosphate have produced decided increases in the yield

of crops, and that the efficiency of this material is increased by the mixing or composting with organic matter. The data presented by the Ohio Station, however, hardly appear to justify in the judgment of the writers a definite conclusion concerning the relative merits of raw rock and acid phosphate even under the conditions of the Ohio experimental work.

PENNSYLVANIA.

The Pennsylvania Experiment Station in 1883[1] undertook what is probably the first recorded experiment with raw rock phosphate conducted by the stations in this country. Since the work was carried on for a year only under conditions which were not controlled, the results do not warrant repetition.

A field experiment to test the fertilizer value of various phosphates was also begun by the Pennsylvania station[2] in 1883, and continued on the same field till the close of 1895, a period of 13 years.

The field selected for this experiment has a slight and uniform slope to the southeast. "The soil of the plots is a so-called limestone clay formed from the decomposition of the surrounding and underlying rock, which is largely a magnesian limestone. It has the general appearance of a clayey loam. During 1880 and 1881 the land was in grass (clover and timothy) and in 1882 in potatoes. No manure was applied to either crop." In 1883, in an effort to determine the uniformity of the field, it was divided into 12 plots of one-twentieth acre each, and planted to oats without the application of any fertilizer whatever.

In Table LVIII the average yield of the plots which subsequently received the same fertilizer treatments are given.

TABLE LVIII.—*Average yield of oats on various plots of experiment field before application of fertilizer.*

Plot letter.	Yield per acre of oats, 1883.
	Bushels.
A and G	45.94
B and H	46.56
C and I	49.38
D and J	49.06
E and K	54.06
F and L	52.81

While it has been repeatedly pointed out that the yields obtained with a single crop can not be taken as proof of the relative natural

[1] Pa. Agr. Expt. Sta., Ann. Rept. for 1884, pp. 33–35 (1885).
[2] Pa. Agr. Expt. Sta., Ann. Repts. for 1884 (1885); 1886 (1887); 1888 (1889); 1889 (1890); 1895 (1896).

fertility of the various plots, the indications are that the average natural productivity of the check plots and those afterwards receiving only a mixture of potash and nitrogen, was greater than that of the plots on which phosphates were applied. It will also be seen that the average yield of the plots afterwards treated with acidulated phosphate was less than the average of any of the other plots.

A regular four-year rotation of wheat, grass, corn, and oats was begun in 1884. The fertilizers were applied only to the wheat and corn crops, being sown broadcast after the field was plowed, and subsequently harrowed in. Muriate of potash and ammonium sulphate were applied to each plot (except the checks) at a rate supplying 100 pounds of potash (K_2O) and 47 pounds of nitrogen, respectively. The phosphates were applied at a rate supplying 32 pounds of phosphoric acid (P_2O_5). During the entire period of the experiment fertilizers have been applied six times.

The average results obtained from duplicate plots are given in Table LIX.

TABLE LIX.—*Average yields of various crops grown in four-year rotation on the same field for a period of 12 years (1884–1895).*

Plot letter.	Fertilizer.	Application per acre.[1]	Average yield (three years) per acre.			
			Wheat, grain.	Grass, hay.	Corn, ears.	Oats.
		Pounds.	*Bushels.*	*Pounds.*	*Bushels.*	*Bushels.*
A and G	Dissolved bone black Muriate of potash Ammonium sulphate	200 200 240	28.23	3,167	48.86	43.42
B and H	Reverted phosphate Muriate of potash Ammonium sulphate	200 200 240	29.89	3,300	49.60	47.10
C and I	Finely ground bone Muriate of potash Ammonium sulphate	150 200 240	31.58	3,365	51.96	49.39
D and J	Finely ground South Carolina rock Muriate of potash Ammonium sulphate	150 200 240	31.56	3,133	47.64	48.24
E and K	Muriate of potash Ammonium sulphate	200 240	30.57	2,492	40.68	45.54
F and L	No fertilizer		22.52	2,048	33.07	38.81

[1] Applications made every other year.

Considering now the average yield of each crop from the variously treated plots during the 12 years in which the fertilizer effects were studied, we find that larger yields of wheat (grain) were obtained on the less soluble than on the readily soluble phosphate plots, and that the plots treated with raw rock phosphate compared favorably with those receiving any other form of phosphoric acid, even when the apparent natural fertility of the various plots (as determined by the crop of oats grown in 1883) is taken into consideration.

In the case of hay (grown in 1885, 1889, and 1893) the production on the plots treated with other forms of phosphoric acid showed

to somewhat greater advantage than the raw rock when the apparent natural fertility of the various plots is considered, but the difference between the acid phosphate plots and those treated with raw rock was so slight as to be well within experimental error. All the phosphate plots gave considerably greater yields of hay than those receiving no phosphate.

The corn crops (1886, 1890, 1894) showed their best yields on the plots treated with finely ground bone and reverted phosphate. When the natural (apparent) fertility of the plots is taken into consideration, the acidulated phosphate plots show better yields than the raw rock plots. All the plots treated with phosphates, however, showed considerably greater yields of corn than those receiving no phosphates.

With oats, the ground-bone plots gave on the whole better yields than any of the other phosphate plots, but the raw-rock plots were not far behind and showed to considerably greater advantage than those treated with soluble phosphate.

In summing up the results of this experiment, Hess[1] of the Pennsylvania station, concludes that, considering the cost of practically equal quantities of phosphoric acid in its various forms, ground bone and raw rock phosphate gave the largest returns for the money invested, "thus indicating that the insoluble phosphoric acid is of more value as a manure than is often supposed * * *."

While the results do seem to show that raw rock phosphate had a distinctly beneficial effect on this field, the increases in yield appear to the writers out of proportion to the six light applications of this material employed, since the total quantity of phosphoric acid thus applied (provided none was removed or lost) would not be sufficient to add 0.01 per cent to the upper 9 inches of an average soil. In other words, raw rock phosphate was applied at the rate of about 54 pounds per acre per annum.

The only other work on raw rock phosphate reported by the Pennsylvania station is a laboratory experiment conducted by McDowell[2] in 1908, to test the effect of rotting manure on the solubility of a natural phosphate. This experiment is mentioned elsewhere in this bulletin.

While the field work of the Pennsylvania station seems to indicate that raw rock phosphate was effective in increasing crop yields, the increases obtained seem so out of proportion to the light applications made that the writers hesitate to attach great importance to the results. As far as they go, however, the data show as great a response from the less soluble as from the more soluble forms of phosphoric acid.

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[1] Pa. Agr. Expt. Sta., Ann. Rept. for 1895, p. 210 (1896).
[2] Pa. Agr. Expt. Sta., Ann. Rept. for 1907–8, pp. 175–178 (1908).

RHODE ISLAND.

The first field work of the Rhode Island station with raw rock phosphate was reported by Flagg and Towar[1] in 1893, and consisted of an experiment conducted for one year only.

In 1912, Wheeler[2] reported results of a three-year experiment with various phosphates. The short duration of these experiments and the absence of check plots make a repetition of the details unjustifiable.

An experiment to test the relative value of various phosphates on limed and unlimed land was begun by the Rhode Island station in 1894.[3] Hartwell[4] published a summary of the results of 20 years.

It is said that the field selected for this experiment was of uniform character, and had not been treated with fertilizer for a number of years, producing only a small crop of hay previously to the plotting of the land. The soil is Miami silt loam, composed of glacial drift of granitic origin. In 1893 the field was divided into 18 plots (the number being increased to 20 the following year), of two-fifteenths acre each, and in order to obtain an index to their natural fertility Indian corn was grown on the entire number without the application of any fertilizer whatever. The yields per plot obtained in this preliminary experiment are given in part in Table LX.

TABLE LX.—*Fertility of plots as measured by the yield of Indian corn in 1893 previous to fertilizer treatment.*

Plot number.	Yield per plot (weight of ear corn).	Relative fertility (plot 67=100).	Plot number.	Yield per plot (weight of ear corn).	Relative fertility (plot 68=100).
	Pounds.	*Per cent.*		*Pounds.*	*Per cent.*
51	159	122	52	132	107
53	124	95	54	103	84
55	140	108	56	95	77
57	142	109	58	73	59
59	127	98	60	86	70
61	79	61	62	90	73
63	111	85	64	98	80
65	114	88	66	146	119
67	130	100	68	123	100

An inspection of Table LX will show that the yields of the odd numbered plots (which were subsequently limed) were in nearly every instance greater than the even numbered plots (which received no subsequent applications of lime). It will also be seen that plots 61 and 62 which afterwards received applications of "floats" gave smaller yields of corn than any of the other plots with the exception of plots 58 and 60.

While the yields obtained in only one year can not be taken as proof of the relative natural fertility of the various plots, the indications are that plots 61 and 62 were poorer than most of the others in the field including the check or no phosphate plots.

[1] R. I. Agr. Expt. Sta., 5th Ann. Rept., pp. 159–160 (1893).
[2] R. I. Agr. Expt. Sta., Bul. No. 148, pp. 21–29 (1912).
[3] R. I. Agr. Expt. Sta., 7th Ann. Rept., p. 122 (1894).
[4] R. I. Agr. Expt. Sta., Bul. No. 163 (1915).

In Table LXII showing the yields of crops obtained during the first period (five years) of the experiment it has been assumed that the preliminary corn crop of 1893 is an index of the natural fertility of the experiment field. This assumption may not be justified, but it serves to show what different conclusions may be drawn, depending on the method employed in comparing field results.

The actual yields therefore have been recalculated on the basis of the apparent natural fertility of the plots as determined by the 1893 corn crop. By subtracting this value from the actual yield the gain due to the fertilizer treatment has been determined and recorded under the heading " Calculated Increase."

This method of comparison is not used in the second and third periods of the experiment, since any initial inequalities in the field were probably modified by five years of fertilization.

The application of fertilizers was begun in 1894. At this time one-half of the plots (odd numbers) were limed at the rate of 1 ton per acre. Similar applications were made to the same plots in 1903, and again in 1911. The plots having even numbers have received no lime whatever during the experiment. Ample amounts of soluble potash and nitrogen carriers were applied to all plots (limed and unlimed) each year. For the first five years, 1894 to 1898, inclusive, the various phosphate carriers were applied in quantities representing at that time equal money values. In 1899, however, it was decided that in view of the fluctuations in the price of the various phosphates it would be wiser to equalize the amount of phosphoric acid on each plot. This equalization, though not completed till 1902, was brought about by ceasing the applications of the insoluble phosphates, but continuing to apply the more soluble phosphates.

From 1902, up to the close of 1913, no phosphate whatever was applied to any of the plots.

The experiment, therefore, may be divided into the three following periods: First, from 1894 to 1898, inclusive, when equal money values of the several phosphates were applied. During this period phosphoric acid was added in the form of raw rock phosphate in considerably greater quantities than in the form of the readily soluble or available phosphates. Second, from 1899 to 1902, inclusive, when the phosphoric acid applications were being equalized on all the plots; and, third, from 1903 to 1913, inclusive, when the residual effects of equal amounts of phosphoric acid in the different forms were being studied.

In the following table, which is taken from Bulletin No. 163 of the Rhode Island station, the rate of application (per one-tenth acre) of the various phosphates, up to the close of 1898, are given. The applications of all the phosphate carriers except raw rock were then continued until the amount of phosphoric added to each plot was the same. This equalization was completed in 1902.

TABLE LXI.—*Sources and amounts of phosphoric acid applied to the different plots*[1] *(1894–1898).*

Plot numbers.	Source of phosphoric acid.	Cost per ton as source of phosphoric acid.	Application of the phosphate per 1/10 acre.			Phosphoric acid applied in the 5 years, 1/10 acre.	Cost of the phosphoric acid.
			1894.	1895.	Total for 1896, 1897, 1898.		
		Dollars.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Dollars.*
51, 52	Dissolved bone black	15.00	60.0	60.0	60.0	31.8	1.35
53, 54	Dissolved bone	14.00	50.4	55.0	45.0	25.0	1.05
55, 56	Dissolved phosphate rock	13.00	92.7	120.0	73.1	44.5	1.86
57, 58	Fine ground bone	19.00	42.3	43.9	43.9	35.0	1.24
59, 60	Thomas slag phosphate	14.00	76.6	66.0	66.0	38.4	1.46
61, 62	Raw phosphate rock	11.00	92.7	94.1	94.1	73.9	1.54
63, 64	Raw Redonda phosphate	15.00	52.8	52.9	52.9	56.0	1.19
65, 66	Roasted Redonda phosphate	33.00	33.0	33.0	33.0	45.3	1.63
67, 68	{No phosphate	......	......	......	......	......	......
	{Double superphosphate	37.00	......	31.1	25.7	[2] 26.5	[2] 1.05

[1] The dimensions of each plot are 30 by 193.6 feet, giving an area of two-fifteenths of an acre; but, in harvesting, the crop on the edges and ends of the plot is usually eliminated and the product from only one-tenth of an acre is weighed.

[2] During four years instead of five, since double superphosphate was not included in the experiment until 1895.

At the close of the first period of the experiment it will be seen that approximately twice as much phosphoric acid had been added in the form of raw rock as in other forms. The crops grown during this period were corn in 1894, oats in 1895, and hay in 1896, 1897, 1898. The yields of the various plots are given in detail in Table LXII.

TABLE LXII.—*Yields of corn, oats, and hay obtained during the first period of experiment (1894–1898).*

[Yields given in pounds per one-tenth acre.]

Source of phosphoric acid.	Corn, 1894.				Oats, 1895.				Hay, 1896, 1897, 1898.			
	Limed.		Unlimed.		Limed.		Unlimed.		Limed.		Unlimed.	
	Actual yield.	[1] Calculated increase due to treatment.	Actual yield.	[1] Calculated increase due to treatment.	Actual yield.	[1] Calculated increase due to treatment.	Actual yield.	[1] Calculated increase due to treatment.	Actual yield.	[1] Calculated increase due to treatment.	Actual yield.	[1] Calculated increase due to treatment.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Dissolved bone black	339	100	278	125	118	61	96	59	1,649	107	712	495
Dissolved bone	270	84	202	82	96	51	101	72	1,463	262	601	430
Dissolved phosphate rock	297	85	245	135	103	52	113	86	1,621	256	680	524
Fine ground bone	200	−14	170	76	87	36	84	63	1,771	394	948	828
Thomas slag phosphate	242	50	178	78	94	48	91	66	1,685	447	1,096	954
Raw phosphate rock	110	−10	146	42	70	41	76	50	1,699	928	832	684
Raw Redonda phosphate	108	−59	110	−4	61	21	50	22	1,129	55	385	123
Roasted Redonda phosphate	178	6	99	−71	41	0	53	11	1,568	456	392	150
No phosphate	196	......	143	......	47	......	35	......	1,264	......	203	......
Double superphosphate	......	......	......	......	82	......	80	......	1,464	......	371	......

[1] Values given in this column obtained by subtracting from actual yields calculated yields as determined by corn crop of 1893. Actual yields—(Check plot yield×relative fertility)=calculated increase.

A study of Table LXII will show that in 1894, the first year of the experiment, the plots receiving applications of raw rock phosphate gave no increase in the yield of corn, even when the probable difference in the natural fertility of the raw rock plots and the check plots is taken into consideration. The soluble phosphate plots (both limed and unlimed) on the other hand gave substantial increases in yield over the check plots. The following year (1895) the yields of oats on the raw rock phosphate plots exceeded that of the no phosphate plots by a considerable margin, and during the next three years of the first period, the yield of hay on the raw rock phosphate plots (both limed and unlimed) surpassed the yield, not only of the check plots, but of the soluble phosphate plots as well, indicating that the ground raw rock was becoming increasingly effective.

Owing to the change in the plan of the experiment the plots were again left in grass in 1899. It was intended to equalize the phosphoric acid applications on all the plots (except the checks) this year, but owing to a mistake the additions of phosphoric acid in other forms was not brought up to that already applied in the form of raw rock until 1902.

No separate figures are given for the grass crop of 1899, but in 1900 the land was plowed, treated with adequate quantities of muriate of potash and nitrate of soda, and planted to corn. The following year (1901) miscellaneous crops were grown in each series in rows extending across the plots.

In 1902, the fourth year of the second period, the plots were planted in soy beans. The results of this second period of the experiment including the years 1900, 1901, and 1902 are given in Table LXIII.

TABLE LXIII.—*Yields of crops obtained during second period of experiment (1899–1902).*

Treatment.	1900: Corn, yield per acre.		1901: Miscellaneous crops.[1]		1902: Soy beans, yield per acre.	
	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
	Bushels.	*Bushels.*	*Per cent.*	*Per cent.*	*Bushels.*	*Bushels.*
Dissolved bone black	71.1	54.7	304	409	27.5	23.3
Dissolved bone	75.6	63.2	327	366	29.3	26.8
Acid phosphate	78.5	70.9	250	395	27.7	25.3
Fine ground bone	84.0	69.8	329	440	29.3	27.5
Basic slag meal	79.4	65.6	336	444	29.8	27.3
Floats	82.3	67.8	243	382	26.5	23.6
Redondite (raw)	76.4	54.3	93	177	17.2	16.0
Redondite (roasted)	82.6	54.1	257	226	24.6	19.1
No phosphates	75.1	48.1	100	100	16.7	14.2
Double superphosphate	78.3	50.9	279	143	25.3	19.7

[1] Relative yields of miscellaneous crops, taking no phosphate plot as 100.

For the second year of the second period of the experiment when the plots were in corn, the raw rock phosphate plot (limed) exceeded

the yields of all the soluble phosphate plots and was only surpassed in actual yield by the plot treated with fine ground bone. Raw rock also ranked among the highest of the unlimed plots, exceeding in yield the plots treated with dissolved bone black, dissolved bone and double superphosphate.

During the third year of the second period, however, when miscellaneous crops were grown the plots treated with the more available and soluble phosphates showed to greater advantage. A point unfavorable to the less soluble phosphates in this experiment is the fact that many of the miscellaneous crops were cut and weighed before maturity. Since acid phosphate undoubtedly gives greater early stimulation than the raw phosphates, the effect of the former was possibly more marked than it would have been had the crops been allowed to mature.

The results with soy beans during the fourth and last year of the second period of the experiment were also more favorable to bone meal, slag, and the soluble phosphates than to the ground raw rock, both on the limed and unlimed series, but the floats gave greatly increased yields over the no-phosphate plots. Large amounts of all phosphates, except raw rock phosphate, were added this year, in order to bring about the equalization of phosphate applications. It is rather surprising, therefore, that the plots so treated should not have given much greater increases for this year than the raw rock plots to which nothing had been added since 1898.

The third period of the experiment began in 1903, when 19 miscellaneous crops were again grown across the plots in both series, a few rows only being devoted to each crop. In 1904, oats were grown and harvested as hay, and in 1905 and 1906, the field was in hay. In 1907, miscellaneous crops were again planted across the plots. Whitecap corn and a few rows of turnips were grown in 1908. In 1909, all the plots were planted in potatoes, which were followed by rye. The rye was harvested in 1910, and Hungarian grass planted. In 1911, oats were grown followed by rowen, and in 1912 and 1913 the field was again in hay. The yields obtained from the various plots during this third period of the experiment are given in detail in Table LXIV.

TABLE LXIV.—*Yields of crops grown during third period (1903–1913).*

Treatment.	1903: Miscellaneous crops.[1]		1904: Oat hay, yield per acre.		1905: Hay, yield per plot.		1906: Hay, yield per plot.		1907: Miscellaneous crops.[1]		1908: Corn, yield of ears per plot.		1909: Potatoes, yield per plot.		1910: Rye and Hungarian hay.[1]		1911: Oats, yield per plot.		1912: Hay, yield per plot.		1913: Hay, yield per plot.		1913: Turnips.[1]	
	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
	P. ct.	*P. ct.*	*Tons.*	*Tons.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*P. ct.*	*P. ct.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*P. ct.*	*P. ct.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*P. ct.*	*P. ct.*
Dissolved bone black	555	272	3.98	2.16	634	461	367	303	204	220	445	423	1,359	903	290	270	75	97	580	290	640	440	489	1,026
Dissolved bone	740	408	4.45	3.15	570	460	320	338	219	335	465	438	1,293	1,150	263	202	68	108	550	230	580	290	255	376
Acid phosphate	641	402	4.30	3.15	555	513	350	343	207	246	416	436	1,180	1,003	233	187	72	107	535	270	570	330	126	438
Fine ground bone	741	412	3.95	3.18	538	468	368	383	242	322	426	475	1,082	1,103	249	218	46	113	545	320	570	350	312	505
Basic slag meal	656	388	4.25	3.70	593	473	353	367	222	302	422	485	1,172	1,162	266	227	48	117	590	370	580	390	269	965
Floats	319	302	3.38	2.70	540	465	350	390	192	275	408	448	987	924	193	141	85	101	510	280	560	360	293	426
Redondite (raw)	99	197	2.30	1.40	460	458	298	327	97	120	243	290	683	438	75	57	75	85	400	220	540	360	55	79
Redondite (roasted)	309	182	3.48	1.45	540	458	298	327	182	142	486	325	1,199	423	240	169	80	100	580	340	660	320	229	176
No phosphate	100	100	2.50	0.70	491	354	330	360	100	100	301	244	729	356	100	100	84	42	400	240	530	360	100	100
Double superphosphate	590	146	3.57	1.70	570	480	405	420	205	164	458	396	1,145	636	207	219	98	67	620	400	770	430	148	478

[1] Relative yields of crops taking "no phosphate" plot as 100.

Considering the results obtained during the third period of the experiment the yields of miscellaneous crops in 1903 were on the whole considerably greater on the soluble-phosphate plots and those treated with basic slag and ground bone than on the raw rock phosphate plots.

In 1904 the raw-rock plots (limed and unlimed) gave smaller yields of oat hay than any of the soluble-phosphate plots, with the exception of double acid phosphate (unlimed.) The yields of hay from the raw-rock plots, however, in 1905 and 1906 compared quite favorably with those of the other phosphate plots.

The yields of most of the miscellaneous crops grown in 1907 were greater on the soluble phosphate, bone, and basic-slag plots than on those treated with raw rock phosphate, but the average yield obtained on plots treated with the latter material were very much greater than those of the check plots.

In 1908 the yield of whitecap corn from the raw-rock plot (unlimed) was greater than that from any of the soluble-phosphate plots, but did not equal the yields of the ground-bone and basic-slag plots. On the limed series, however, the yields of corn were greater on the basic-slag, bone, and soluble-phosphate plots. The results with the few rows of turnips grown this same year on the limed series were more favorable to raw rock phosphate than to any other phosphate application, but on the unlimed series basic-slag treatment showed to much greater advantage.

In 1909 the yield of potatoes from the raw-rock plot (limed and unlimed) was exceeded by all the other phosphate plots except raw Redonda, dissolved bone black (unlimed) and double superphosphate (unlimed). The rye which was planted in 1909 and harvested in 1910 gave considerably better yields on the plots (limed and unlimed) treated with slag, bone, and the soluble phosphates than on the raw-phosphate plots. The same was true of Hungarian hay which followed rye. In 1911, however, the yields of oats on the raw-rock plots compared very favorably with the yields from the plots which had received equal amounts of phosphoric acid in other forms. The hay crops in 1912 and 1913 were somewhat better on the slag, bone, and soluble-phosphate plots than on those treated with raw rock, but the yields of turnips this same year from the raw-rock plots compared favorably with those from the plots receiving other phosphates, except dissolved bone black and basic slag (unlimed).

In summing up the results of this long-time experiment it can be said that distinct increases in yields were obtained from the use of raw rock phosphate. In nearly every case where this material was applied in quantities supplying from two to three times as much phosphoric acid as acid phosphate it compared favorably with the

latter material after lying in the soil for some time (two years), and becoming thoroughly distributed through tillage and cultivation.

On bringing up the applications of slag, bone, and acid phosphate to the point where equal amounts of phosphoric acid were added to all plots except the checks, the latter forms were on the whole somewhat more effective than raw rock phosphate, particularly on the limed plots. This, however, is what might be expected in view of the greater solubility of bone, slag, and the acidulated phosphates and the greater ease with which they are distributed in the soil. Indeed, it seems rather surprising that raw rock phosphate should have given such continued increases in yield when the total quantity added in 20 years (provided none was removed by the crop grown) was sufficient to add less than 0.03 per cent of phosphoric acid to the upper 9 inches of a soil of medium texture. When using a phosphatic fertilizer, the effectiveness of which depends upon heavy applications, the use of 2,000 or 2,500 pounds per acre in 20 years seems a very light application.

A pot experiment with the soil taken from the 20 plots of the experiment field just described was undertaken by the Rhode Island station in 1905,[1] just three years after the phosphoric acid applications had been equalized on all the phosphate plots. Limed soil was taken from the odd numbered plots and unlimed soil from the even numbered plots.

The results obtained in the growing of wheat for two weeks were fairly well in accord with the field results obtained on the same soil when equal applications of phosphoric acid were employed. In both cases the beneficial effect of lime was very marked. The short duration of this experiment, however, renders detailed discussion unwarranted.

The results of the Rhode Island station's work, in the opinion of the writers, point strongly to the value of raw rock phosphate as a fertilizer. Even when applied under such adverse conditions as in the station's 20-year experiment the raw rock phosphate plots gave very marked increases over the no-fertilizer plots, and in many instances surpassed those treated with more soluble phosphates. The writers feel, however, that the data afforded by this experiment are insufficient to warrant a strict comparison of the relative merits of the various forms of phosphoric acid.

SOUTH CAROLINA.

While the South Carolina Experiment Station has reported 23 experiments with raw rock phosphate, 20[2] of these have been conducted for one year only and 2[3] for a period of three years.

[1] R. I. Expt. Sta., Bul. No. 109 (1905).

[2] S. C. Agr. Expt. Sta., Bul. No. 5 (1889); Bul. No. 12 (new series) (1893); Bul. No. 14 (new series), p. 4 (1893); Bul. No. 18 (new series) (1894).

[3] S. C. Agr. Expt. Sta., Bul. No. 2 (new series) pp. 80–82 (1891).

A more valuable experiment with raw rock phosphate is that reported by Keitt[1] in 1914. While the results of four years' work in the growing of corn and cotton on plots treated with various phosphates alone, and in combination with other fertilizer materials have been reported, this work is said to be only preliminary and is therefore not discussed here.

None of the experiments of the South Carolina station have been continued long enough to warrant discussion and therefore no conclusions may be drawn concerning the value of raw rock phosphate as a fertilizer.

TENNESSEE.

The Tennessee station has published the results of 10[2] field experiments with raw rock phosphate. Seven of these experiments cover periods of only one to two years.

The average results obtained in three experiments covering periods of from three to four years and conducted by, or under the direction of the State station, were published by Mooers[3] in 1912. A rotation of cowpeas and wheat was practiced in these experiments and four different types of phosphate fertilizers were tested both on limed and unlimed plots.

The beneficial effect of liming on these three forms was quite marked except in the case of the raw rock phosphate and basic slag plots. The latter material appears to have been the most effective of all the phosphates, owing in part no doubt to the free lime which it contained.

If the average yields of all three forms are considered, the raw rock plots (unlimed) compare very favorably with the acid phosphate (unlimed) plots, but where lime was applied the average yields were considerably more favorable to acid phosphate.

If, however, the average yields obtained on the station farm only are considered (the experiment at this place having been conducted the longest) the raw rock phosphate plots compare favorably with those receiving acid phosphate and bone both on limed and unlimed land.

These three experiments have not been running long enough to give conclusive evidence on the relative values of the four forms of phosphoric acid used and therefore are not repeated in detail, but the indications are that applications of raw rock phosphate were effective in increasing the yield of various crops.

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[1] S. C. Agr. Expt. Sta., Bul. No. 178 (1914).

[2] Tenn. Agr. Expt. Sta., Ann. Rept. 1885–1886, pp. 100–112 (1886); Bul. No. 2, vol. 13, pp. 11–14 (1900); Bul. No. 1, vol. 16, pp. 14–16 (1903); Bul. No. 86 (1909); Bul. No. 90 (1910); Bul. No. 92 (1911); Bul. No. 96 (1912).

[3] Tenn. Agr. Expt. Sta., Bul. No. 96, pp. 15–24 (1912).

VIRGINIA.

In an article entitled "A Study of the Effect of Fertilizers on the Soluble Plant Food in the Soil, and on the Crop Yield," Ellett and Hill,[1] showed the impracticability of accurately correlating the solubility of phosphates in a certain conventional solvent with their availability to crops under soil conditions. The analytical work connected with the problem was checked against field results with corn extending over a period of five years.

The soil of the field used in this experiment was derived from the Shenandoah limestone, and consisted of a light gray (Hagerstown) loam, ranging from 6 to 10 inches in depth and underlain by a reddish yellow clay subsoil. "The cropping history of this particular soil is not definitely known, but it has probably been under cultivation for not less than 75 years." The total phosphoric acid content (0.113 per cent) was ample, though only 0.07 per cent was shown by the ordinary hydrochloric acid digestion method of analysis.

The annual application per acre of the various fertilizers and the yields of corn (grain) obtained are shown in Table LXV. Since none of the other phosphates was used in connection with carriers of nitrogen and potash, a comparison between them and acid phosphate is only possible where the latter was used alone. The results obtained on plots treated with mixtures of acid phosphate, nitrogen, and potash are, therefore, omitted in the table.

TABLE LXV.—*Yields per acre of corn obtained on plots receiving various forms of phosphoric acid (1907–1911).*

Plot number.	Fertilizer	Application per acre.	1907	1908	1909	1910	1911	Average yield for five years.
		Pounds.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1	Acid phosphate	600.0	46.61	45.00	42.95	37.50	30.53	40.51
2	do	200.0	41.79	48.21	41.79	30.53	34.82	39.43
3	Floats	99.6	46.61	46.61	39.64	25.71	36.43	39.00
4	do	99.6	43.93	53.35	39.11	27.32	34.28	39.59
5	Thomas slag	192.0	41.79	44.46	39.11	19.28	31.60	35.24
6	do	192.0	37.50	41.79	30.00	21.42	31.07	32.35
7	Acid phosphate	400.0	39.11	38.57	32.68	14.82	21.43	29.32
11	Check		43.93	40.18	36.96	24.64	19.29	33.00
12	do		40.71	51.43	39.64	24.10	24.10	35.99
13	do		42.86	45.00	36.43	24.10	30.00	35.67
14	do		42.86	46.61	43.39	28.92	37.50	39.85
18	Lime	1,200.0	43.93	53.57	52.50	39.65	47.68	47.46
19	Check		44.46	47.14	39.64	30.00	34.82	39.21
20	do		42.86	53.57	46.08	30.00	35.36	41.57
23	do		40.71	62.14	38.03	15.00	37.50	44.59
24	do		40.18	31.07	36.96	[1] 7.85	33.21	35.35

[1] Not included in average.

The results obtained in this experiment are very confusing. If the difference in the yields of the check plots be considered for any

[1] Va. Agr. Expt. Sta. (Blacksburg). Ann. Rept. for 1911–12, pp. 116–132 (1913).

single year, it appears that their relative natural fertility varied greatly, yet check plot No. 23, which yielded 3 less bushels of corn than check No. 12 in 1907, exceeded the yield of this latter plot in 1908, by nearly 11 bushels. These same inconsistencies are noticeable throughout the table. The plot receiving a fair application of lime gave better yields than any of the phosphate treated plots, yet the plots treated with basic slag, which is richer in lime than any of the other phosphates, gave poorer yields than either of the "floats" plots and two out of three of the acid phosphate plots. While the raw rock phosphate plots produced on the whole better results than those treated with either of the other forms of phosphoric acid, the average yield of corn on these plots for the entire five-year period was only 1 bushel greater than the average on all the check plots.

In view of the fact that the applications of raw rock were entirely too light to prove effective and moreover were only from one-sixth to one-half as great as those of acid phosphate, no comparison between the two forms of phosphoric acid would be justified even had the soil been responsive to phosphate treatment. Practically the only conclusion to be drawn from these results is that all forms of phosphoric acid were ineffective.

Ellett and Hill[1] also published the results of four pot experiments with various phosphates on different but important Virginia soil types. The tests were made in the greenhouse and were similar in all respects. Twenty-five pounds of each soil type was taken for each pot, the fertilizer added, and the whole thoroughly mixed. The moisture content was maintained in each pot throughout the experiment at about one-half the water holding capacity of each soil. The seed planted, the number of plants per pot, and the fertilizer treatments were the same for each series of pots. Every treatment was run in quadruplicate. The various soil types employed were as follows: (1) A typical Coastal Plain sandy soil, low in phosphoric acid; (2) a Piedmont "Red Lands" clay soil well supplied with phosphoric acid and potash but low in nitrogen; (3) a Piedmont chocolate-colored clay loam suitable for general agriculture, with rather high contents of potash and phosphoric acid, but low in nitrogen; (4) a Piedmont gray sandy soil lower in its content of phosphoric acid and potash than the chocolate clay loam and very poor in nitrogen.

The results of the pot experiments with these soils are given in Table LXVI.

[1] Va. Agr. Expt. Sta. (Blacksburg). Bul. No. 200, p. 24 (1912).

TABLE LXVI.—*Yields of oats obtained in four pot experiments with various types of soil.*

Fertilizer.	Application per acre.	Yields of oats, average of four pots.			
		Coastal Plain soil.	Piedmont, Red Lands soil.	Piedmont, chocolate soil.	Piedmont, gray soil.
	Pounds.	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Acid phosphate	200	37.9	42.9	37.5	38.1
Floats	120	30.9	43.2	28.6	35.7
No fertilizer	....	33.9	46.5	32.8	34.4
Nitrate of soda	100	34.1	54.6	45.2	39.1
Potassium sulphate	100	32.3	44.0	45.5	37.8
Nitrate of soda Potassium sulphate	100 100	34.5	50.0	47.4	51.5
Nitrate of soda Acid phosphate	100 200	45.5	60.1	57.0	51.5
Nitrate of soda Potassium sulphate Acid phosphate	100 100 200	46.8	65.0	51.0	53.0
Lime	....	25.8	....	....	....

With the exception of the Coastal Plain soil, the various types seemed to respond more readily to nitrogen than to phosphoric acid applications. On the basis of equal applications of phosphoric acid, however, the acid phosphate pots gave considerably better yields than those treated with raw rock phosphate, the latter material apparently producing no effect whatever. The rate of application, however, was so low,[1] and the duration of the experiments so brief, that appreciable increases in yield could hardly be expected.

In 1913 Johnson,[2] of the Virginia Truck Station, published the results of a fertilizer experiment in the growing of kale. This experiment was the outgrowth of one begun in 1908, the object of which was to determine the relative value of various fertilizer materials and the best quantities to apply, and also to determine the relative value of stable manure and clover as sources of humus both with and without lime.

The fertilizer treatment was continued over a period of five years, but the results of only one year (1913) are recorded. The ground raw rock phosphate plots compared very favorably with the acid phosphate plots, but the best yields were obtained from the use of bone products, owing probably to the nitrogen contained in the latter. However, the limited data recorded render the results of this experiment inconclusive.

The work of the Virginia station has not as yet been extensive enough to justify a comparison of acid phosphate with ground raw rock phosphate, particularly as in every experiment the applications of the latter material have been too light to get the full benefit from such an insoluble substance.

[1] The amount of phosphoric acid applied was sufficient to add about 0.0014 per cent of P_2O_5 to the first 9 inches of a soil of medium texture.

[2] Va. Truck Expt. Sta., Bul. No. 9 (1913).

WASHINGTON AND WEST VIRGINIA.

Only one field experiment[1] with raw rock phosphate has been published by the Washington Experiment Station, and four[2] by the West Virginia station. None of these have been continued beyond one year, so they are not repeated in detail.

WISCONSIN.

Four field experiments[3] with raw rock phosphate have thus far been reported by the Wisconsin Experiment Station, but since none of them have been continued beyond two years they are not considered in detail in this bulletin.

The excellent work of Truog,[4] Tottingham and Hoffman[5] and Fred and Hart[6] on the solubility and availability of phosphates and the mutual action of bacteria and phosphates on one another is discussed elsewhere in this bulletin.

While the results of the Wisconsin station's work on ground raw rock are too limited to draw any definite conclusions, the indications point to its value as a fertilizer on peaty soils. No comparison of acid phosphate and raw rock phosphate, however, is warranted.

EXPERIENCE OF FARMERS WITH RAW ROCK PHOSPHATE AS A FERTILIZER.

While the field work of the State experiment stations is as a rule much more valuable to the student of agriculture and their results much easier of interpretation, at the same time the experience and opinions of a large number of progressive farmers who have given raw rock phosphate a fair trial, are of considerable value and worthy of serious consideration.

In order to determine the sentiment of such farmers toward raw rock phosphate a letter and set of questions was sent to each of 1,000 farmers in various parts of the country who had ordered more than one shipment of this material. It might be argued that this method of choosing names was hardly fair and on its face favorable to raw rock phosphate, since the fact that the orders for this material were repeated indicates very strongly that the consumers considered it effective. On the other hand it is probable that those who sent in but one order for raw rock phosphate reached an unfavorable decision concerning its fertilizer value before they had given it a fair

[1] Wash. Agr. Expt. Sta., Popular Bul. No. 49 (1912).

[2] W. Va. Agr. Expt. Sta., Bul. No. 28, pp. 57–60 (1892).

[3] Wis. Agr. Expt. Sta., 22d Ann. Rept., pp. 275, 281 (1905) : Bul. No. 147, pp. 27–34 (1907) ; 24th Ann. Rept., pp. 261–271 (1908) ; Bul. No. 202, pp. 8–11 (1911) ; Bul. No. 205, pp. 9–12 (1911).

[4] Wis. Agr. Expt. Sta., Research Bul. No. 20 (1912).

[5] Wis. Agr. Expt Sta., Research Bul. No. 29 (1913).

[6] Wis. Agr. Expt. Sta., Research Bul. No. 35 (1915).

trial, and therefore their opinions would be less valuable than those who had used the material through a term of years.

Replies were received from 315 farmers, most of them in the Middle West where raw rock has been tried out much more extensively than in the East or South.

Of this number 219 or 69.6 per cent reported favorable results from the use of raw rock phosphate, 55 or 17.4 per cent were doubtful about its value, and 41 or 13 per cent regarded the material unfavorably.

Many of the responses were very incomplete and in most instances no check plots were employed. In no case was a reliable comparison made between acid phosphate and raw rock.

A summary of the data obtained is given in Table LXVII (p. 114).

SUMMARY.

Much doubt and difference of opinion exists concerning the fertilizer value of ground raw rock phosphate, but the use of this material has slowly increased until the annual consumption is now in excess of 91,000 tons.

Numerous experiments have been conducted with this material in the field, greenhouse, and laboratory, and while many of these experiments are of very little value, others warrant serious consideration. To avoid confusing the reader by a mass of data of doubtful value no field experiments of less than five years' duration have been recorded in detail in this bulletin.

The use of ground raw rock phosphate as a fertilizer in this country dates back to the early days of the South Carolina phosphate industry, but the Pennsylvania State Experiment Station recorded the first field experiment with this material in 1885. Since that date the work has been taken up by practically all of the stations east of the Mississippi River and a few of those west.

Since natural phosphate of lime or phosphorite is very resistant to weathering influences, it can not ordinarily be expected to yield its phosphoric acid readily to the soil solution, but by subjecting it to some chemical treatment by which it is rendered water soluble, its effectiveness is greatly increased. On the other hand, if the rock is ground to an impalpable powder (floats) and applied to the soil in such large quantities that an enormous surface is exposed to the action of the soil waters, a considerable amount will eventually be dissolved. Since carbon dioxide (in solution) and bacteria also affect the solubility of raw rock phosphate, it is reasonable to expect the latter to be more effective on soils high in organic matter. This effect may be expected to be particularly marked on soils of low phosphoric acid content.

TABLE LXVII.—*Summary of replies from 315 farmers in 28 States concerning value of raw rock phosphate as a fertilizer.*

State.	Total number of replies.	Farmers favoring use of raw rock phosphate.							Farmers doubtful about the value of raw rock.							Farmers against the use of raw rock.						
		Total number.	Number using it at rate of 250 pounds or more per acre.	Number applying it with organic matter.	Number using check plots.	Number using it for 1 year only.	Number using it for 2 years only.	Number using it for 3 or more years.	Total number.	Number using it at rate of 250 pounds or more per acre.	Number applying it with organic matter.	Number using check plot.	Number using it for 1 year only.	Number using it for 2 years only.	Number using it for 3 or more years.	Total number.	Number using it at rate of 250 pounds or more per acre.	Number applying it with organic matter.	Number using check plots.	Number using it for 1 year only.	Number using it for 2 years only.	Number using it for 3 or more years.
Alabama	4	3	2	2	0	0	1	2	0	0	0	0	0	0	0	1	1	0	0	1	0	0
Arkansas	1	1	(1)	(1)	0	(1)	(1)	(1)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Colorado	1	1	(1)	(1)	0	(1)	(1)	(1)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Connecticut	4	3	1	1	0	1	1	1	0	0	0	0	0	0	0	1	(1)	(1)	0	1	0	0
Delaware	1	1	1	(1)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Georgia	8	7	7	4	0	3	0	4	0	0	0	0	0	0	0	1	1	0	0	1	0	0
Illinois	105	79	78	39	2	7	5	64	16	16	8	0	(1)	4	1	10	10	0	0	8	1	1
Indiana	24	16	14	9	0	3	2	10	4	(1)	(1)	0	1	0	2	4	4	4	0	0	0	4
Iowa	4	0	0	0	0	0	0	0	3	1	(1)	0	1	0	0	1	1	1	0	1	0	0
Kansas	3	1	1	1	0	0	0	1	1	(1)	(1)	0	(1)	0	0	1	1	0	0	1	0	0
Kentucky	14	13	11	9	0	3	0	10	1	1	1	0	0	0	1	0	0	0	0	0	0	0
Louisiana	4	4	2	3	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	4	2	2	1	0	0	1	1	0	0	0	0	0	0	0	2	1	2	0	1	0	0
Michigan	15	9	9	7	0	0	1	6	5	5	4	0	2	1	0	1	1	0	0	0	1	0
Mississippi	6	5	4	3	0	0	1	4	0	0	0	0	0	0	0	1	1	1	0	1	0	0
Missouri	6	2	2	1	0	0	0	1	1	0	0	0	1	0	0	3	2	1	0	2	0	1
New Jersey	3	2	2	1	0	1	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0
New York	14	8	6	7	0	2	0	6	2	2	0	0	0	0	1	4	4	3	0	4	0	0
North Carolina	15	14	12	10	0	1	3	9	1	1	1	0	1	0	0	0	0	0	0	0	0	0
Ohio	18	7	5	5	0	0	1	6	7	2	3	0	5	1	1	4	2	1	0	0	0	0
Pennsylvania	20	12	9	10	1	2	4	6	7	4	7	0	1	1	2	1	1	0	0	0	0	1
South Carolina	5	5	5	5	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tennessee	5	3	3	2	0	1	0	2	0	0	0	0	0	0	0	2	1	0	0	1	1	0
Texas	4	2	2	0	0	1	0	1	0	0	0	0	0	0	0	2	0	1	0	2	0	0
Vermont	1	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0
Virginia	14	9	7	6	1	1	1	6	3	2	1	0	1	0	2	2	2	2	0	0	0	1
West Virginia	3	2	1	2	0	0	0	2	1	1	1	0	0	0	1	0	0	0	0	0	0	0
Wisconsin	9	8	6	7	0	1	0	5	1	0	0	0	1	0	0	0	0	0	0	0	0	0

[1] Not stated.

The problem of determining the agricultural value of ground raw rock phosphate has been attacked through the media of laboratory, greenhouse, and field experiments. The laboratory investigations may be classified under the four following heads: (1) Determination of composition of rock. (2) Methods of determining availability of phosphates. (3) Effect of fineness of division on its solubility or availability. (4) Effect of organic fermentation on its solubility and availability.

In the analysis of rock phosphate for direct application to the field it is often only necessary to determine the quantity of phosphoric acid present in the sample.

Practically all of the methods so far proposed to determine the availability of phosphates are empirical and none of them which recommend that the phosphate be kept in contact with a definite quantity of solvent for a limited time can show any sharp distinction between the amounts of phosphoric acid available and unavailable under soil conditions.

The fineness to which rock phosphate is ground has been found to have a very important influence on its solubility in certain conventional solvents as well as upon its availability to crops. Greater yields of peas, barley, rape, and oats were obtained where floats were applied than where the phosphate was applied in coarser particles. The solubility of the very finely ground material in certain conventional solvents was also found to be considerably greater than when the rock was less finely ground.

It has been pretty well demonstrated that bacteria have an appreciable effect upon natural phosphates. When bacterial activity is accompanied by the formation of acid (carbon dioxide) the solvent action exerted on the rock phosphate is quite marked. In the case of fermenting manure, however, it has been found that the manure organisms fix or absorb phosphoric acid from natural phosphates, the latter actually showing a decreased solubility after being in contact with the manure for some time. But it has further been shown that the availability of the phosphorus in the cells of such organisms is as great as that in acid phosphate. Moreover, after fermentation has ceased, the phosphorus is released in forms soluble in carbonated waters. In nearly all of the experiments conducted to determine the effect of fermentation on rock phosphate, some conventional solution, usually a weak acid, has been employed to measure the availability of the altered phosphate. It has already been pointed out that most of these solvents do not serve as indices to the phosphoric acid available under soil conditions.

The presence of decaying organic matter in the soil, accompanied as it always is by greater bacterial activity and an increased amount

of carbon dioxide, is a potent factor in rendering rock phosphate available to crops.

The advantage of pot and greenhouse work lies in the fact that by the exercise of the greatest care the conditions under which the crops are grown may be, to a large extent, controlled.

The final proof of the value of raw rock phosphate as a fertilizer must rest upon field experiments. A large amount of field work has been conducted with this material under a variety of conditions, but unless the numerous factors influencing crop yields be taken into consideration the results appear very conflicting. In considering the results of field experiments, careful attention must be given to the following factors: (1) Uniformity of experiment field, (2) topography and drainage conditions, (3) physical and chemical composition of the soil, (4) previous treatment of the field, (5) climatic conditions, (6) injuries from disease, insects, and animals, (7) kind of crops grown and selection of seed, (8) rate of application and uniform distribution of phosphates, (9) methods of comparing raw rock with other phosphates, (10) effect of other fertilizers, (11) number and distribution of plots, (12) duration of the experiment.

Two hundred and thirty-two field experiments with raw rock phosphate have been reported by the State experiment stations. Of this number only the 37 experiments given detailed consideration in this bulletin were conducted for a period of five years or longer. A summary of these 37 field tests is given in Table LXVIII, but in view of the fact that nearly all of these tests were conducted under different conditions and involve the consideration of variable factors, it is obviously impossible to classify the data in such a way as to give each experiment its proper weight. The classification given in the table therefore is in some instances necessarily arbitrary.

Out of the 37 tests given in Table LXVIII, 22 were carried on with a view to comparing the relative merits of raw rock and acid phosphate. The conditions under which such a comparison was attempted varied greatly, but it may be said that in a general way 13 of these experiments or 59.1 per cent gave crop yields as favorable to raw rock as to the more soluble form of phosphoric acid. Of the 9 experiments in which raw rock did not compare favorably with acid phosphate, 2 were conducted on fields unresponsive to phosphate treatments, and 2 gave results which could be classed as either favorable or unfavorable, depending on the method of interpretation employed.

Of the 15 experiments in which no comparison between ground raw rock and acid phosphate was attempted, 11 or 73.3 per cent gave results strongly indicating beneficial effects from the applications of the former material, and 2 of the remaining 4 experiments were

TABLE LXVIII.—*Summary of results of field experiments with raw rock phosphate conducted by the State stations over periods of from 5 to 20 years.*

State.	Total number o experiments.	Experiments comparing raw rock with acid phosphate.			Experiments making no comparison of raw rock with acid phosphate.			Experiments where raw rock applications were relatively light.			Experiments where raw rock applications were liberal.			Experiments where raw rock was used in connection with organic matter.			Apparent cumulative effect.		
		Total.	Number favorable.	Number unfavorable.	Total.	Number favorable.	Number unfavorable.	Total.	Number favorable.	Number unfavorable.	Total.	Number favorable.	Number unfavorable.	Total.	Number favorable.	Number unfavorable.	Evident, number.	None, number.	Unknown, number.
Alabama	0																		
Connecticut	0																		
Delaware	0																		
Florida	0																		
Georgia	0																		
Illinois	12	3	2	[1] 1	9	7	[1] 2	4	4		8	6	[1] 2	11	9	[1] 2	8	[1] 3	1
Indiana	2	2	1	[1] 1							2	1	[1] 1	2	1	[1] 1			2
Kentucky	1	1		1							1	1		1	1		1		
Louisiana	3	3	1	2				2		2	1	1					1	1	1
Maine	2	2	1	1				2	2								1		1
Maryland	2	2	2								2	2		1	1			1	1
Massachusetts	2	2	1	[2] 1				1	1		1	1		1	1				2
Mississippi	2	2	1	1				2	2										2
Missouri	4				4	2	2	4	2	2				4	2	2	4		
New Jersey	0																		
New York	0																		
North Carolina	0																		
Ohio	4	2	1	[2] 1	2	2		3	2	[2] 1	1	1		3	3		1		3
Pennsylvania	1	1	1					1	1									1	
Rhode Island	1	1	1					1	1								1		
South Carolina	0																		
Tennessee	0																		
Virginia	[1] 1	[1] 1	[1] 1					[1] 1		[1] 1								[1] 1	
Washington	0																		
West Virginia	0																		
Wisconsin	0																		
Total	37	22	13	9	15	11	4	21	15	6	16	13	3	23	18	5	17	7	13

[1] Soil not responsive to phosphate treatment.
[2] Figures for this experiment are favorable according to one method of computation and unfavorable according to another.

conducted on fields showing little or no response to phosphate treatment.

In 21 experiments the applications of raw rock phosphate were relatively light (250 pounds or less per acre), yet 15 of these experiments or 71.4 per cent showed distinctly favorable increases in yields on the plots treated with this material.

In 16 experiments where the raw rock phosphate applications were more liberal, 13 or 81.3 per cent resulted favorably to raw-rock phosphate, and the remaining 3 experiments were conducted on soils showing little or no response to phosphate treatment.

Raw rock phosphate was applied in connection with organic matter in 23 experiments. Out of this number 18 or 78.3 per cent gave distinctly favorable results, and of the 5 remaining experiments 3 were conducted on fields unresponsive to other forms of phosphoric acid.

In regard to the cumulative effect of ground raw rock phosphate it may be said that in 17 instances (46 per cent of the entire number of experiments) there was evidence of greater availability after raw rock had been applied for a number of years. In 13 out of the remaining 20 experiments the data are not sufficient to give evidence on this point, and in 4 out of the 7 cases where no cumulative effect was shown the soils were not responsive to phosphate treatments.

In order to determine the sentiment toward ground raw rock phosphate as a fertilizer a letter and set of questions were sent to each of 1,000 progressive farmers who had used the material for one or more years. Out of 315 replies, 219 farmers or 69.6 per cent were favorable to its use, 55 or 17.5 per cent were doubtful concerning its value, and 41 or 13 per cent regarded the material unfavorably.

CONCLUSIONS.

The data presented in this paper were gathered in order that those interested in the use of raw rock phosphate might draw their own conclusions. The classification of the experimental work according to states was made so that the experience with this material in each particular locality might be studied in the least possible time. Some of the experiments, however, undoubtedly conflict and in others, results which on close analysis agree fairly well, appear on the surface contradictory. It is hoped, however, that by carefully considering the factors influencing crop yields as outlined in page 18 to page 28, and applying them to the individual experiments much confusion can be avoided and the reader be able to obtain a fairly clear idea of the value of the results.

While the writers do not wish to influence the judgment of anyone reading this paper, they feel, after carefully weighing the data contained therein, that certain general conclusions are justified.

(1) The conventional laboratory methods so far proposed for determining the availability of phosphoric acid in various phosphates, while of some use, do not necessarily serve as an index to its availability under soil conditions.

(2) Field experiments conducted for only one or two years, where the various fertilizer treatments are not replicated or where no index is given to the relative natural fertility of the various plots employed, have little or no meaning.

(3) The application of liberal and even medium quantities of raw rock phosphate to most soils produces an increase in the yields of many crops the first year.

(4) The effectiveness of raw rock phosphate depends largely on its thorough distribution in the soil, this distribution being brought about by liberal applications of very finely divided material and thorough cultivation.

(5) The presence of decaying organic matter in the soil increases the effectiveness of ground raw rock phosphate, owing probably both to greater bacterial activity and the higher content of carbon dioxide in such soils.

(6) As a corollary of (4) and (5) the effectiveness of raw rock phosphate is usually increased after remaining in the soil for a year or more.

(7) Most crops respond more quickly to applications of acid phosphate than to bone, basic slag, or raw rock phosphate. Therefore, where the early stimulation and quick maturity of the crop are the main considerations, acid phosphate is probably the best form of phosphoric acid to apply.

(8) Field experiments in which raw rock phosphate and acid phosphate are compared on the basis of equal applications of the two materials or on equal applications of phosphoric acid in the two forms result often in favor of acid phosphate (particularly when such experiments are conducted for a short period), as in order to get the maximum benefit from the natural phosphates they must be applied at a rate far exceeding that at which acid phosphate proves effective.

(9) The question whether increases in yield can ordinarily be produced more economically by applications of the soluble or relatively insoluble phosphates must be considered in a measure a separate problem for each farmer, since it depends on a number of factors of which the most important are the nature of the soil, the crop system employed, the price of the various phosphates in each particular locality, and the length of the growing season.

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